MONITORING ECOLOGICAL CHANGE IN THE ARCTIC PARKLANDS

Vital Signs Monitoring Plan for the Arctic Network: Phase I Report

Diane M. Sanzone, Ph.D.
Arctic Network Coordinator
National Park Service
201 First Ave.
Fairbanks, AK 99701

Scott D. Miller
Arctic Network Data Manager
National Park Service
201 First Ave.
Fairbanks, AK 99701

Steven B. Young, PhD
Director Emeritus
Center for Northern Studies
Sterling College
479 Cross Rd.
Wolcott, VT 05680

With contributions by:
Andrew Balser (UAF), Cathy Cahill (UAF), Jefferson Jacobs (NPS),
Torre Jorgensen (ABR), Jennifer Mitchell (UAF/NPS),
Peter Neitlich (NPS), and Jennifer Allen

30 September 2005

Table of Contents

"What would you attempt to do if you knew you could not fail?"

—Author Unknown

"Go out on a limb. That is where the fruit is."

—Jimmy Carter

Preface

In 2003, the Arctic Network (ARCN) began the process of planning a long-term ecological monitoring program for the five farthest north national parklands, encompassing over 19.3 million acres. This report summarizes two years of progress in designing that program. Completion of a final monitoring plan for the network is anticipated by the end of 2008 and involves three phases. Phase 1, described in Chapters 1 and 2 of this report, involves defining goals and preliminary objectives; identifying, evaluating, and synthesizing existing data; and developing draft conceptual models. Phases 2 and 3 will involve selection of indicators ("vital signs") and design of sampling protocols. The material presented in this report is preliminary and may be revised as additional background information is compiled and the monitoring program develops. Revisions to Chapters 1 and 2 will appear in the Phase 2 report.

In Chapter 1 of this report, we define the purpose and scope of the ARCN monitoring program; explain the process that the network followed in designing the program; describe the ecosystems of ARCN; elucidate potential resource concerns for the parks; define network objectives for freshwater, coastal, and terrestrial ecosystems; provide an exhaustive list of potential monitoring questions for ecosystems of interest, and summarize data mining and joint arctic initiatives. In Chapter 2, we use conceptual models to explain our understanding of the ecosystems of ARCN, current and future anthropogenic impacts to those ecosystems, and the possible ecosystem and landscape-scale consequences of those impacts.

The overall process that ARCN has followed in planning, designing, and implementing its vital signs monitoring program is described in more detail at the NPS Inventory and Monitoring website (http://science.nature.nps.gov/im/monitor/index.htm). This report, along with all appendices and other information, is available on the Arctic Network website (http://www1.nature.nps.gov/im/units/arcn/index.cfm).

Acknowledgements

Thank you to President Jimmy Carter for signing the most significant land conservation measure in the history of our nation, the Alaska National Interest Lands Conservation Act (ANILCA), into law. Without your dedication to these public trust resources the 19.3 million acres of national parklands that make up the Arctic Network (ARCN) would not exist as such.

The authors thank Jefferson Jacobs, Andrew Balser, Torre Jorgensen, Jennifer Mitchell, Cathy Cahill, Peter Neitlich, and Jennifer Allen for helping with various sections of this report. Torre Jorgenson's and Jennifer Mitchell's help with conceptual models was invaluable.

We thank our past and present technical committee members Jim Lawler, Peter Neitlich, Amy Larsen, Jennifer Allen, Brad Shults, Thomas Liebscher, Thomas Heinlein, Ken Adkisson, Lois Dalle-Molle, Karen Oakley and Sara Wesser for participation in meetings and scoping workshops. Without their thoughtful input and dedication, this document would not have been possible.

Thank you GAAR, WEAR, and AKRO staff for your support of ARCN. We are especially indebted to Monica Cross, Robyn Burch, and Jan Maslen for their administrative support of ARCN. In addition to the technical committee, the resource staff in WEAR and GAAR have helped guide our program and given us useful input at various stages, especially Fred Andersen, John Burch, Melanie Cook, Donna DiFolco, Eileen Devinney, Bob Gal, Nikki Guldager, Linda Hasselbach, Dave Krupa, Charlie Lean, and Jeff Rasic. Thank you to Amy Larsen, Jim Lawler, Jennifer Allen, and Thomas Liebscher for thoughtful review of earlier versions of this report.

Many thanks to all of our workshop participants from the local communities, other agencies, and academia. Your input has been essential in helping design a scientifically sound, ecologically based, and management-relevant monitoring program for ARCN.

We thank the current and past members of the ARCN board of directors: Sara Wesser, Dave Spirtes, Thomas Heinlein, George Helfrich, Julie Hopkins, Brad Bennett, Dave Mills and Bob Winfree for their thoughtful insights and support of the Arctic Network.

We are also grateful to Steve Fancy for his unflagging support, guidance, and vision for the networks.

This document would not have been possible without the hard work and attention to detail that the Artic Research Consortium of the U.S. (ARCUS) put into helping us organize the ARCN scoping workshops, notebooks and Phase 1 Report. We especially thank Birte Horn-Hanssen, Janet Daley, and Wendy Warnick. Thank you also to Sue Mitchell, now at Inkworks, and April Crosby of Crosby and Associates.

Last but not least, we thank the other three Alaska network coordinators, Maggie MacCluskie, Alan Bennett, and Chiska Derr for their support, camaraderie, and setting the example in Alaska.

Executive Summary

- The National Park Service's Inventory and Monitoring (I&M) Program is vital to fulfilling NPS's mission of protecting and preserving the natural resources of the national park system unimpaired for the use and enjoyment of current and future generations. Established in 1992, the purpose of the I&M program is to "develop scientifically sound information on the current status and long term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems." The principal functions of the program are to: (1) gather baseline information about park ecosystems, (2) develop techniques and strategies for monitoring ecological communities, and (3) provide crucial scientific information to park managers so that better-informed scientifically sound management decisions can be made.
- National parks with significant natural resources have been grouped into 32 monitoring networks linked by geography and shared natural resource characteristics. The network approach facilitates collaboration, information sharing, and economies of scale in natural resource monitoring. Parks within each of the 32 networks work together and share funding and professional staff to plan, design, and implement an integrated long-term monitoring program.
- The Arctic Network (ARCN) includes five NPS system units (Figure 1): Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park and Preserve (GAAR), Kobuk Valley National Park (KOVA), and Noatak National Preserve (NOAT). Collectively these units represent approximately 19.3 million acres, or roughly 25% of the land area of NPS-managed units in the United States.
- Administratively, the parklands in ARCN are managed as three units: (1) Western Arctic Parklands (WEAR), which consists of one monument (CAKR), one park (KOVA) and one preserve (NOAT) is managed by a superintendent in Kotzebue; (2) BELA, which is managed by a superintendent in Nome; and (3) GAAR, which is managed by a superintendent in Fairbanks, with field offices in Bettles and Coldfoot. The park headquarters for all five parks are outside the park boundaries and the parks themselves are accessible only by airplane, boat, or on foot. This creates a unique and interesting challenge for creating a long-term monitoring program.
- The large land area of ARCN parks and the differences in resource management priorities among parks were perceived as the greatest challenges facing the network. However, during our park scoping workshops and superintendent interviews, we found that the ARCN parks share the same resource management concerns and monitoring needs.
- The National Park Service's Arctic Network (ARCN) mission is to create a long-term monitoring program that deepens the understanding of the boreal and arctic ecosystems represented in the parks, integrates knowledge of the park ecosystems with the circumpolar North and the world in general, and informs wise management decisions and the preservation of park values.
- ARCN held a series of scoping workshops to provide a forum for NPS resource managers and scientists to discuss ideas for building a statistically sound, ecologically based, management-relevant, and affordable monitoring program for the Arctic Network (ARCN) of parks. The scoping workshops for ARCN were designed to gain expert advice from a broad array of scientists who have performed or are familiar with ecological research in northern Alaska. The input from these meetings were used to (1) develop a set of conceptual models of the natural and anthropogenic features and processes within the parks, (2) develop a list of monitoring objectives for ecosystems of significance,

and (3) identify an exhaustive list of candidate attributes or components ("vital signs") to monitor that would provide reliable signals about condition of the ecosystem.

- The ARCN monitoring program will be designed around the five service-wide goals. In addition, the ARCN staff and outside experts drafted the following criteria for a successful monitoring program for the difficult-to-access remote parklands of the Arctic. We thought the program would be successful if it was foundational; relevant to arctic ecosystems and arctic ecosystem science and monitoring; of interest to local, circumpolar, and global communities; took an integrative and efficient approach; was collaborative, cost-effective, and comprehensive; was achievable (realistic regarding access, logistics, etc.); valuable to park managers and scientists; and complemented the "infrastructure capital."
- ARCN data mining efforts have focused on two fronts: assembling a natural resource bibliography and identifying sources of high-quality inventory and monitoring data and collaborations. In 2004 we made great progress on populating the national Inventory and Monitoring bibliography, NatureBib, with publications about the arctic park ecosystems. ARCN also began data mining efforts with the goal of identifying present and historical resource inventories and monitoring efforts. While this effort is still beginning and will likely be an ongoing process through the life of the program, we have made a preliminary list of agencies, programs, existing ecological inventories, and long-term studies that may be of value to the Arctic Network.
- Throughout the last decade, there have been a number of major international research and monitoring initiatives of significance to ARCN. In order for ARCN to develop a successful monitoring program, participation in national and international initiatives will be of the utmost importance (e.g., International Polar Year; High Latitude Ecological Observatory Network (HLEO-NEON).
- The Arctic Network held three scoping workshops, which were designed, in part, to help network staff develop a set of conceptual models of the natural and anthropogenic features and processes of the enormous areas included in the parks. Each of the three workshops tackled one of three areas of interest to ARCN: freshwater, coastal influenced, and terrestrial ecosystems. Conceptual models developed during the scoping workshops were reproduced in a computer graphics program and placed in workshop output summary documents. Information from the workshops was then interpreted and summarized into 3-D landscape-scale conceptual ecosystem models. Our hope is that the models presented in Chapter 2 will (1) help to describe the complex ecosystems of ARCN; (2) elucidate current and potential anthropogenic stressors to ARCN ecosystems, (3) suggest potential mechanisms by which these anthropogenic stressors could impact ARCN ecosystems, and (4) help lay the foundation for monitoring critical aspects of the environment of the parks.

Chapter 1

Introduction and Background

"Sentiment without action is the ruin of the soul.
One brave deed is worth a thousand books."

—Edward Abbey

Importance of Monitoring

Effective management of America's parklands requires not only a broad understanding of their enabling legislation and purpose, but also demands a clear, scientifically derived concept of their past and potential future condition. In recognition of the fact that such critical information is frequently unavailable for park managers who must solve real-world problems using anecdotal, qualitative, or incomplete data, the National Park Service has committed to providing high-quality information about the condition of park resources through its Inventory and Monitoring (I&M) Program.

Established in 1992, the purpose of the I&M Program is to "develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems." In order to accomplish this mission, the I&M program set out to:

1. provide a consistent database of information about our natural resources, including species diversity, distribution, and abundance (12 Basic Inventories);

and

2. determine the current condition of our resources and how they are changing over time.

Such information will help judge the efficacy of management decisions, elucidating potential threats to valued ecological components, and determining which trends in a fundamentally dynamic system are natural and which may be human-induced and potentially deleterious. Similarly, some systems are naturally variable, and a monitoring program can help determine what variation can be expected over an arbitrary time period. Such data can be advantageous in defining what limit of variability may be characterized as impairment. A good monitoring program also recognizes that anthropogenic influences do not respect political boundaries. Baseline inventory and monitoring efforts must therefore be collaborative in nature to provide a better-informed and broader landscape-level spatial perspective to problems that may otherwise be viewed with a more constrained and localized eye.

By approaching ecosystem monitoring with such an innovative, holistic and, by necessity, interdisciplinary approach, the Inventory and Monitoring Program has become a de facto leader, breaking new ground in the realm of ecosystem monitoring. A side consequence of this notoriety is that we will be watched and emulated, resulting in added pressure to get it right the first time through. It is our hope that the care and effort put into this monitoring plan will result in a dramatic improvement in park administrators' ability to make rapid, informed, and beneficial policies to protect park resources, inform visitors about the workings of their park ecosystems and preserve them for future generations.

The Arctic Network

The Arctic Network (ARCN) is one of 32 inventory and monitoring networks nationally and one of four in Alaska. The network includes five NPS units (Figure 1):

- Bering Land Bridge National Preserve (BELA),
- Cape Krusenstern National Monument (CAKR),
- Gates of the Arctic National Park and Preserve (GAAR),
- Kobuk Valley National Park (KOVA), and
- Noatak National Preserve (NOAT).

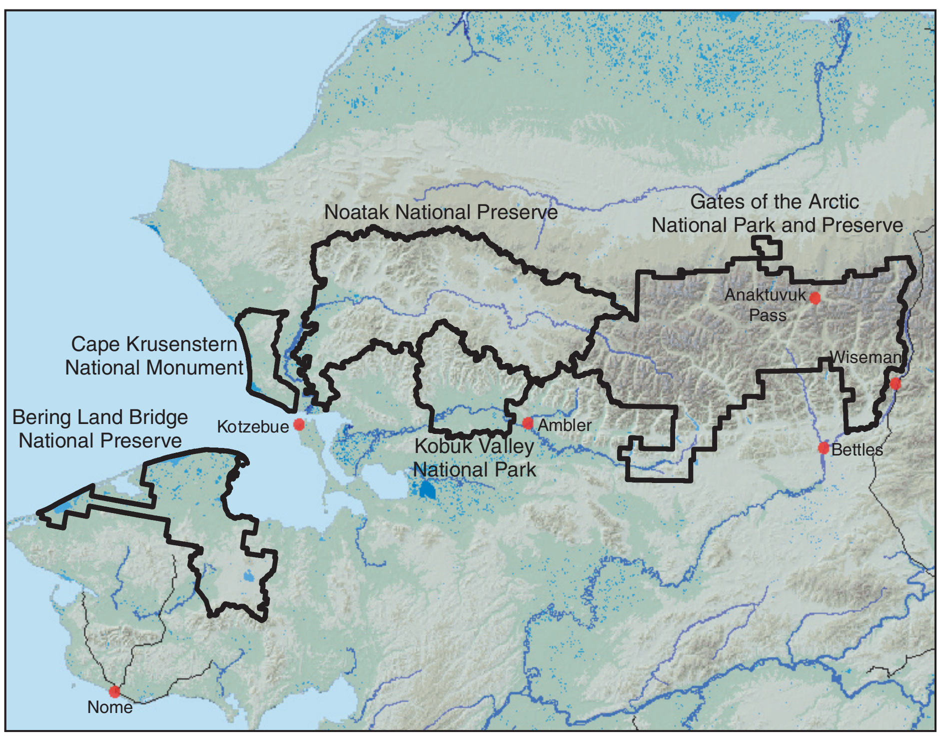


Figure 1. The Arctic Network

Collectively, these units represent approximately 19.3 million acres, or roughly 25% of the land area of NPS-managed units in the United States. GAAR, KOVA, and NOAT are contiguous and encompass a large expanse of mostly mountainous arctic ecosystems at the northern limit of treeline. Immediately to the west of these units lie CAKR and BELA, which border Kotzebue Sound, the Bering Strait, and the Chukchi Sea. BELA and CAKR are similar with respect to their coastal resources and strong biogeographic affinities to the Beringian subcontinent—the former land bridge between North America and Asia. The ARCN park units are not connected to the road system. Much of the ARCN is designated or proposed wilderness.

All of the NPS units within the ARCN parks are relatively recent additions to the national park system. Portions of BELA, CAKR, and GAAR were initially created by presidential proclamation in 1978. All five units were redesignated or created with their present boundaries by the Alaska National Interest Lands Conservation Act (ANILCA) in 1980. The recent origin of these remote and difficult-to-access units, coupled with limited natural resource staffing levels, has left the natural resources in these units relatively under-studied.

Administratively, the parklands in ARCN are managed as three units: (1) Western Arctic Parklands (WEAR), which consists of one monument (CAKR), one park (KOVA), and one preserve (NOAT), managed by a superintendent in Kotzebue; (2) BELA, which is managed by a superintendent in Nome; and (3) GAAR, which is managed by a superintendent in Fairbanks, with field offices in Bettles and Coldfoot. The park headquarters for all five parks are outside the park boundaries and the parks themselves are accessible only by airplane, boat, or on foot. This creates a unique and interesting challenge for creating a long-term monitoring program.

Legislation, Policy and Mandates

The I&M Program is vital to fulfilling the NPS's mission of protecting and preserving the natural resources of the national park system unimpaired for the use and enjoyment of current and future generations. The National Park Service Organic Act of 1916 clearly states that NPS lands will be managed:

> *to promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as to conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.*

More recently, the National Parks Omnibus Management Act of 1998 established the framework for fully integrating natural resource monitoring and other science activities into the management processes of the national park system. The act charges the secretary of the interior to: "continually improve the ability of the National Park Service to provide state-of-the-art management, protection, and interpretation of, and research on, the resources of the National Park System," and to "assure the full and proper utilization of the results of scientific studies for park management decisions."

The lack of scientific information about resources under NPS stewardship has been widely acknowledged as inconsistent with NPS goals and standards. In 1992, the National Academy of Science recommended that, "if this agency is to meet the scientific and resource management challenges of the twenty-first century, a fundamental metamorphosis must occur."

Congress reinforced this message in the text of the FY2000 Appropriations Bill:

> *The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data.*

The nationwide Natural Resource Challenge program was put in place to revitalize and expand the natural resource program of the National Park Service. This effort increased funding to the I&M Program to facilitate improved baseline and long-term trend data for NPS natural resources. To efficiently and fairly use the funding available for inventories and monitoring, the 270 National Park Service units with significant natural resources managed by the service were organized into 32 biome-based networks (Figure 2). Four networks were established in Alaska, clustering park units that share similar ecosystems and mandates (Figure 3). These networks have been designed to share expertise and infrastructure for both biological inventories and development of long-term ecological monitoring programs.

Figure 2. National Inventory and Monitoring Networks

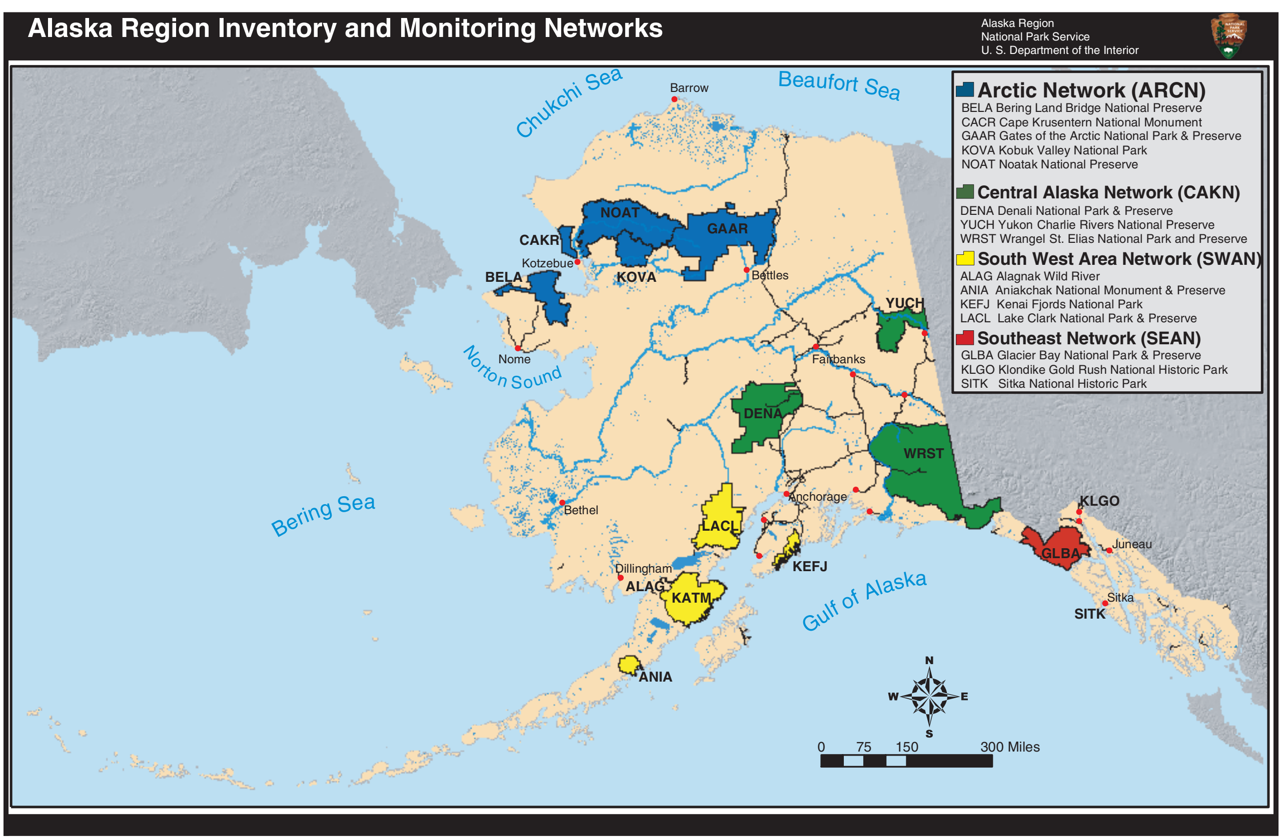


Figure 3. Alaska Inventory and Monitoring Networks

Role of Monitoring in Park Management

The overall goal of natural resource monitoring in the national parks is to develop scientifically sound information on the current status and long-term trends in the composition, structure, and function of park ecosystems and to determine how well current management practices are sustaining those ecosystems.

National Monitoring Goals

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

ARCN's Approach to Designing a Monitoring Program

Our Mission Statement

The National Park Service's Arctic Network (ARCN) will create a long-term monitoring program that deepens the understanding of the boreal and arctic ecosystems represented in the parks, integrates knowledge of the park ecosystems with the circumpolar North and the world in general, and informs wise management decisions and the preservation of park values.

Timeline for ARCN

The Arctic Network received initial funding from the servicewide I&M program to conduct biological inventories in FY2001. In FY2003 ARCN received initial funding for vital signs monitoring. A network coordinator was hired in June 2003 to begin designing the monitoring program. In FY2003, the Board of Directors and Technical Committees were formed and each adopted charters. Also in FY2003, ARCN held park scoping workshops and informally interviewed staff in each of the five parks. In FY2004, the Arctic Network received funds to continue inventories of vascular plants and vertebrates and startup funds for initiating the water quality and vital signs monitoring programs. In FY2004, the network data manager was hired and two of the three scoping workshops were held. In FY2005, the network received full funding for vital signs and water quality monitoring. In 2005, the remaining two scoping workshops were held (Figure 4).

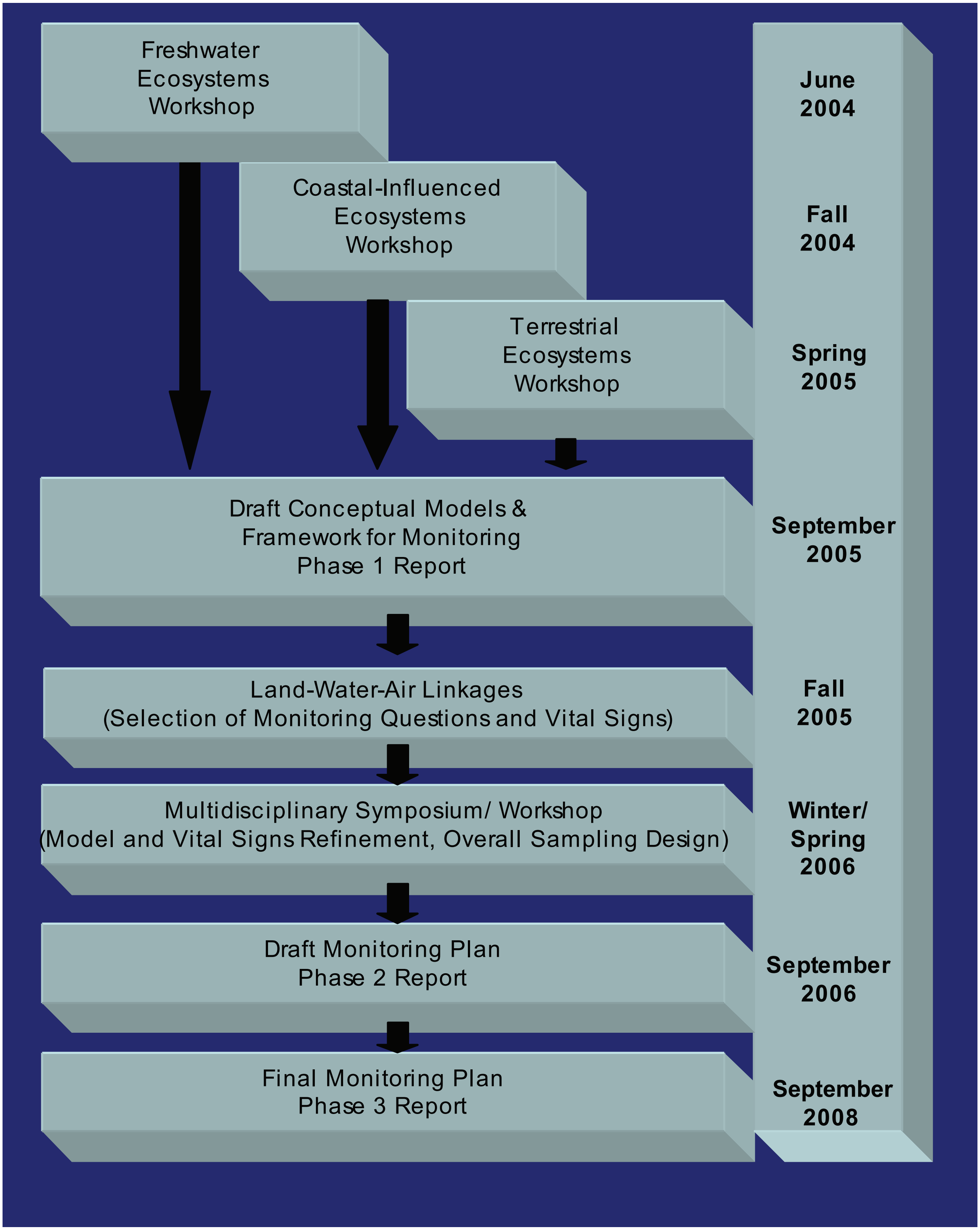


Figure 4. Timeline for ARCN monitoring plan development.

Network Personnel Structure and Function

In order for this program to be highly accessible and useful to park managers, each network was advised to establish a board of directors and technical advisory committee to help plan and implement the monitoring program (Figure 5). The ARCN board of directors consists of three superintendents representing the park units, the Alaska regional Inventory and Monitoring (I&M) coordinator, the ARCN I&M coordinator, and the Alaska regional science advisor. The nine-member technical committee consists of the chiefs of resource management from each park unit, two natural resource scientists from each park unit, a regional fire ecologist, the ARCN I&M coordinator (chair), and the Alaska Cooperative Ecosystem Studies Unit (CESU) coordinator. Aquatic, Coastal, Terrestrial, Land-Air-Water Linkage, Data Management and Administrative Working Working Groups are composed of members of the technical committee and park staff. These smaller working groups advise the network coordinator on specific aspects of network functions. Consultation with scientific experts and peer review has been crucial in the development of this program.

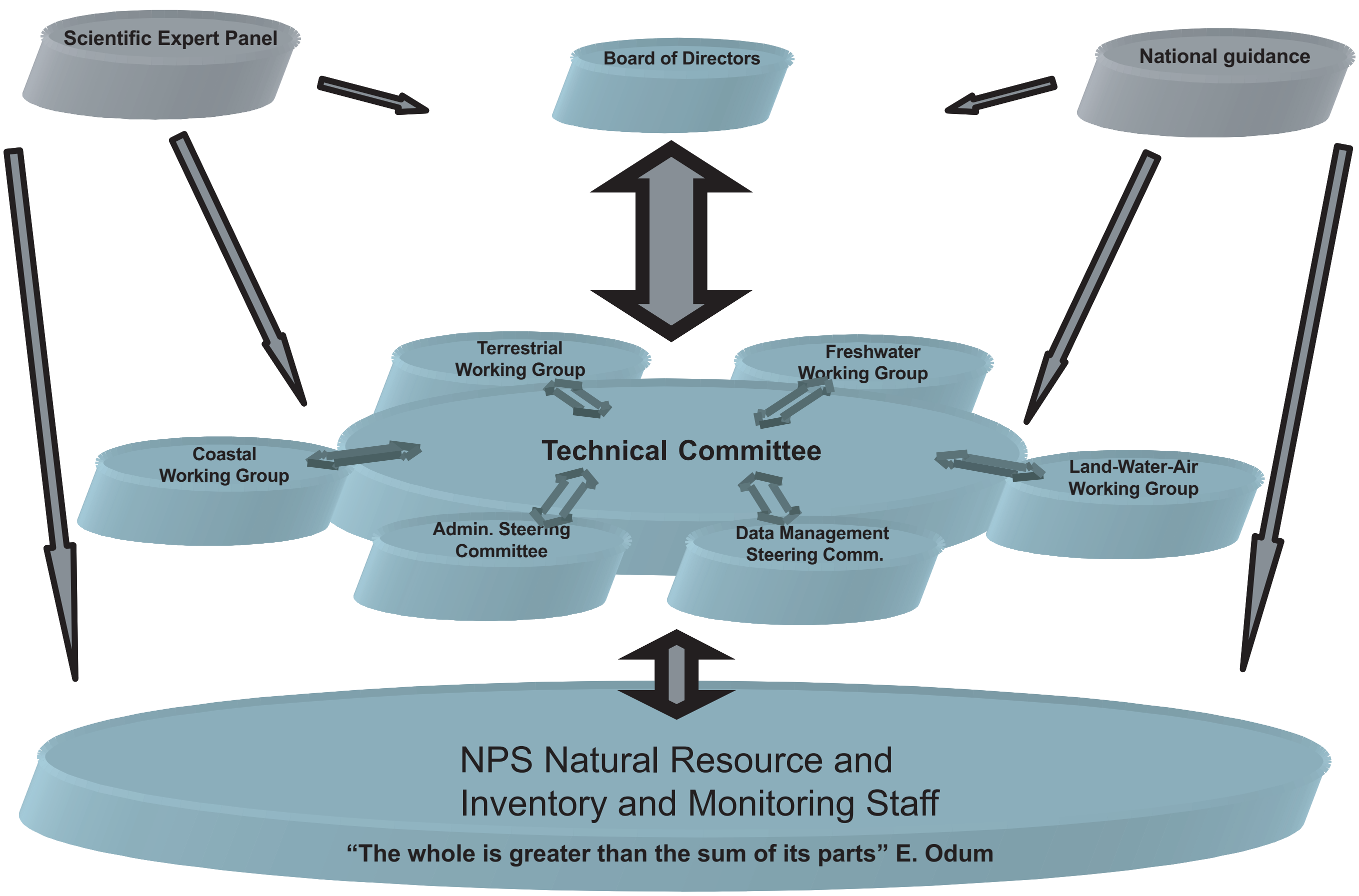


Figure 5. Arctic Network personnel structure.

Planning Process for Developing the ARCN Monitoring Plan

In order to achieve the above goals, the Arctic Network is following the basic approach to designing a monitoring program laid out in the National Framework. The process involves five key steps:

1. Define the purpose and scope of the monitoring program.
2. Compile and summarize existing data and understanding of park ecosystems.
3. Develop conceptual models of relevant ecosystem components.
4. Select indicators and specific monitoring objectives for each.
5. Determine the appropriate sampling design and sampling protocols.

These five steps are incorporated into a three-phase planning process that has been established for the NPS monitoring program (Figure 6). Phase 1 involves defining goals and objectives; beginning the process of identifying, evaluating, and synthesizing existing data; developing draft conceptual models; and determining preliminary monitoring questions. Phase 2 involves refining the conceptual ecosystem models and selecting "vital signs" that will be used as indicators to detect change. Phase 3 of the planning process involves determining the overall sample design for monitoring, developing protocols for monitoring, and producing a data management plan for the network.

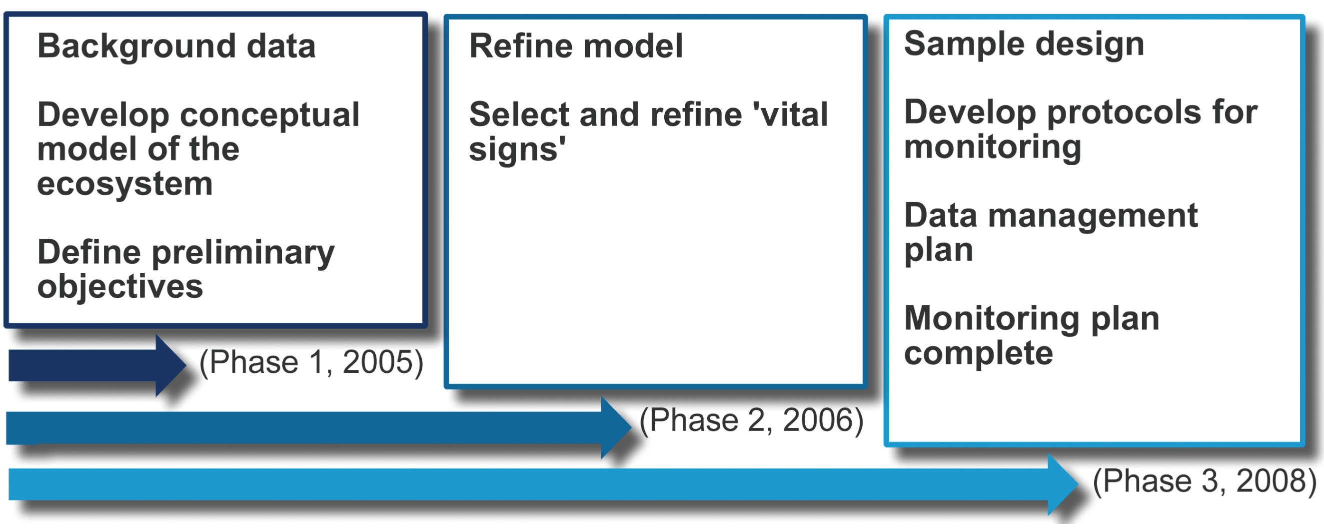


Figure 6. ARCN three-phased approach to monitoring program development.

Scope of the ARCN Monitoring Plan

ARCN held a series of scoping workshops to provide a forum for NPS resource managers and scientists to discuss ideas for building a statistically sound, ecologically based, management-relevant, and affordable monitoring program for the Arctic Network of parks. The scoping workshops for ARCN were designed to gain expert advice from, and initiate longer term consultation with, a broad array of scientists who have performed or are familiar with ecological research in northern Alaska. The input from these meetings were used to: (1) develop a set of conceptual models of the natural and anthropogenic features and processes within the parks (Chapter 2); (2) develop a list of monitoring objectives (see below); and (3) identify candidate attributes or components to monitor that would provide reliable signals about condition of the ecosystem.

Our strategy for this initial set of workshops was to create large scale conceptual models and an exhaustive list of monitoring objectives from participant input. Over time these could be reduced to a more focused set of conceptual models, monitoring objectives, list of priority "vital signs" and eventually a detailed plan for monitoring critical aspects of the environment of the parks. It is expected that the data gathered in this program will contribute to responsible management of the parks so as to conserve their environmental integrity indefinitely. A valuable additional effect of this work should be to provide useful data and insights into the broader concerns of understanding and protection of the environment of the circumpolar north (Figure 7).

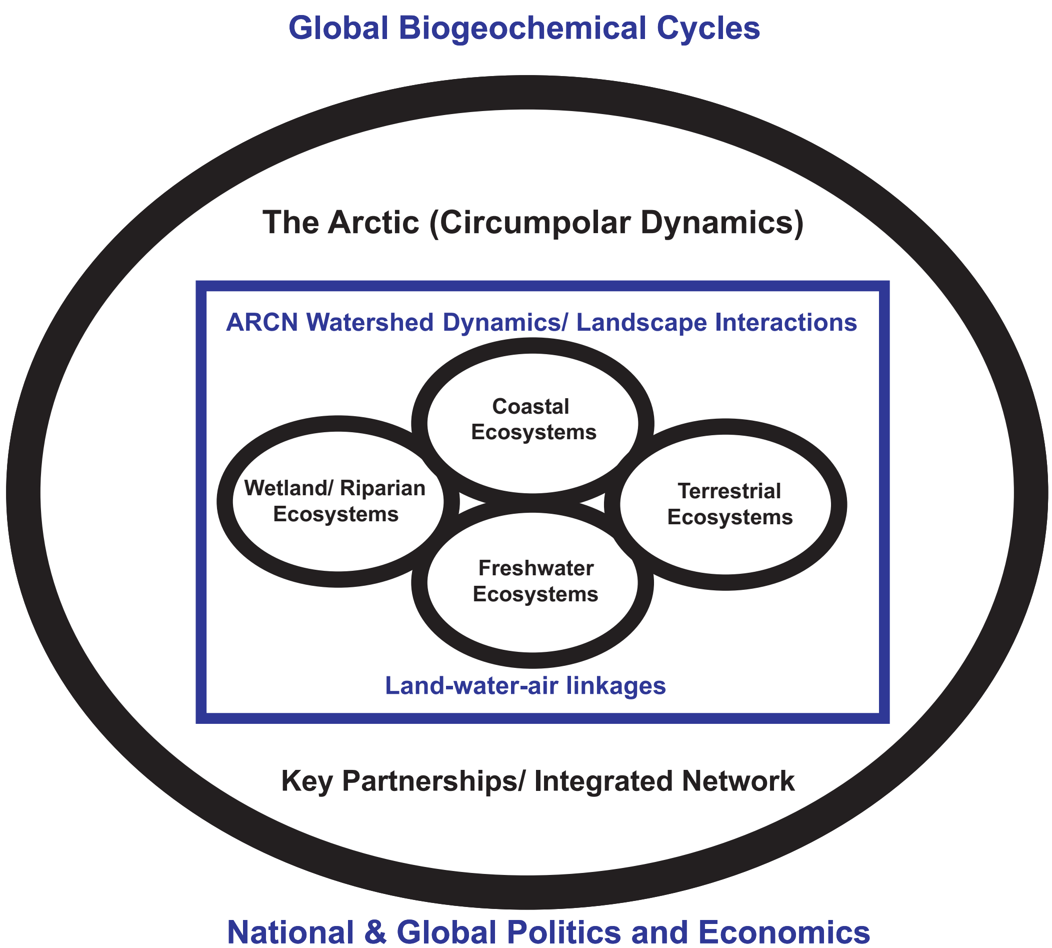


Figure 7. Conceptual model showing how ARCN ecosystems fit within a national and global context.

Long-term monitoring is increasingly recognized as an essential tool for understanding and managing environments at many levels of geographical scale and human use. Since monitoring is essentially a system of sampling, it requires knowledge and judgment on the part of the people who design and carry out the monitoring program. Thus, long-term monitoring is much more than the random gathering of data. Ideally, it is an evolving process that is guided by several concepts:

Efficiency: Monitoring must strive to get the maximum amount of useful information from a sampling system that is limited by factors such as cost, logistical concerns, and availability of trained personnel.

Relation to the broader world: Monitoring benefits from, and provides for, the exchange of useful information with comparable environments, even if they are being managed for different purposes, or have only minimal management programs or plans.

Flexibility: Monitoring plans must be able to incorporate new information and concepts and evolve with increased understanding of the ecosystems under study.

Scale: Monitoring deals with processes that take place over widely varying amounts of time and space. It must be designed to provide information on both local, often rapidly proceeding, processes and those that occur over longer times and/or broader geographical areas.

Dynamism: Monitoring plans must recognize that ecosystems are never static, and that even without anthropogenic impacts, complex changes will always be occurring.

Criteria for a Successful Monitoring Plan in the Arctic Parks

The ARCN Technical Committee and invited scientific experts attending the Freshwater Scoping Workshop realized the enormity of the task of creating a statistically sound, ecologically based monitoring program that would be representative of 19.3 million acres of arctic and subarctic ecosystems. They came up with the following draft criteria for monitoring in ARCN. The list was further reviewed by outside experts attending the Coastal and Terrestrial Ecosystem Workshops. This list will serve as a checklist to determine if proposed monitoring projects meet the goals of the network monitoring program.

List of criteria for a successful approach to monitoring:

- Foundational
- Relevant to arctic ecosystems and arctic ecosystem monitoring
- Of interest to local, circumpolar, and global communities
- Take an integrative and efficient approach
- Collaborative
- Cost-effective

- Comprehensive
- Achievable (realistic regarding access, logistics, etc.)
- Valuable to park managers and scientists
- Complement the "infrastructure capital"

Park Scoping Workshops

In FY2003 and FY2004, the network staff met with park and regional staff in formal and informal settings. In order to involve park staff in the initial stages of developing a monitoring program and determine the real and perceived challenges in "thinking like a network," ARCN staff held park scoping workshops.

The workshops began with an overview of the Natural Resource Challenge, the national goals of the inventory and monitoring program, and our vision for ARCN. A round-table discussion of past, current, and future work of relevance to the monitoring program ensued. We then asked: What are the major ecological drivers in ARCN Parks? What are the current (and future) stressors to ARCN parks? What is the most appropriate time scale for monitoring in the arctic parks? What are the most important stressors to ARCN parklands right now? What are the perceived future impacts to ARCN parklands in the next 10 years, 30 years, 50 years? Staff in all three management units were concerned with the same anthropogenic impacts to park ecosystems (see Chapter 2). A series of nested conceptual models were developed based on input from the park workshops. The scientific experts on the technical committee helped refine these models. The models were then inserted into the formal scoping workshop notebooks to provide necessary background information to scientific experts outside of NPS. The models were reviewed and modified by these experts after the formal scoping workshops (see below).

Before the park miniworkshops, differences in resource management priorities among parks were perceived as the greatest challenges facing the network. However, during our park scoping workshops and superintendent interviews, we found that the ARCN parks share the same resource management concerns and monitoring needs.

Ecosystem Monitoring Scoping Workshops: Freshwater, Coastal, Terrestrial and Land-Air-Water Linkages

The Arctic Network held a series of scoping workshops to provide a forum for NPS resource managers and scientists to discuss ideas for building a statistically sound, ecologically based, management-relevant, and affordable monitoring program for the Arctic Network (ARCN) of parks. In three of these workshops we delineated the landscape into freshwater, coastal-influenced, and terrestrial ecosystems. Although we realize this division is somewhat arbitrary, it enabled us to strategically separate ARCN ecosystems into more manageable subunits for the purposes of discussion. A fourth workshop, land-air-water linkages (LAW), is planned for fall 2005. In this workshop participants will be asked to take a larger, landscape-scale approach to thinking about monitoring in ARCN.

The workshops were built around a series of small working group sessions in which invited experts focused on particular ecological subjects. The overall objectives of the meetings were to: (1) create and refine conceptual models, (2) develop a comprehensive list of potential monitoring questions, (3) identify potential ecosystem attributes ("vital signs"), and (4) determine possible measures of those vital signs. (See workshops appendices 1–6 for more detail.)

To facilitate better discussion during the workshops, the ARCN staff assembled extensive background materials for each of the parks. This background material was put into a scoping notebook and given to each of the participants well in advance of the meeting (Appendices 1, 3, and 5). Included in the notebook were worksheets that helped the participants prepare for the workshop.

Each workshop followed a formula in which the first afternoon and following morning were spent in a large group gaining background information on the specific ecosystem components (e.g., birds, soils, vegetation), the drivers and/or anthropogenic stressors that impact them (e.g., climate, fire, visitor impacts, adjacent North Slope development), and possible ecosystem responses. During the second day the group divided into smaller working groups of 6 to 12 and were given the task of commenting on, revising or replacing existing models as needed for thoroughness, accuracy, descriptive quality, etc. These new and revised models were presented to and further refined by the larger group. The second task on day two was to break up into small groups and with the ecosystem models in mind, work toward developing monitoring questions and proposing preliminary vital signs. Each group then shared its results with the larger group. After reviewing our progress with the whole group, we reconvened in a second working group session. Having heard everyone else's proposed monitoring questions, we identified each group's highest priority questions.

By the end of the third day, we had recorded potential monitoring questions in a database. In addition, we had expert opinions on which questions were the most compelling for the Arctic Network and how we might go about answering them. We also compiled a list of potential partners that may be willing to collaborate and share costs.

Scoping workshop products from each of the workshops were compiled into a workshop summary report (Appendices 2, 4, 6). The summary report included 3-D conceptual models that were created based on input gleaned from the scoping workshops, potential monitoring questions, possible ecosystem components or attributes of interest, and discussion notes. These summary reports were placed on the ARCN web page for further comment and review by all workshop attendees and technical committee members.

Superintendent Interviews

Input from park managers is critical to the success of the ARCN long-term monitoring program. In order to help facilitate the process of gathering information on natural resources of concern in the park units, we set up interviews with current and past superintendents of the five arctic parklands. Personal interviews with each of the current superintendents were conducted during 2005. Because of the high turnover in superintendents in four of the five park units, we also interviewed past superintendents who were accessible (i.e., still living and still working for NPS).

We asked each superintendent 10 questions that we felt would help us better understand the current and future challenges facing the management of their parklands and how best to make the ARCN monitoring program relevant to their park(s) (Appendix 7).

Regional Integration Among Networks: Landscape-Scale Collaboration

Because Alaska parks present unique challenges, regional collaboration is of the utmost importance. It will enable an integrated approach to better use science results and management resources. For example, because many of the Alaska parks occupy large land areas, have little or no resource staff, and are logistically difficult to monitor, it may be useful to adopt statistically rigorous sampling designs from another networks, share staff and expertise, or adopt successful protocols. In some cases, working with the same collaborators and resource staff will facilitate the larger scale contribution that the I&M program can make to monitoring in Alaska.

Collaboration with the Other 31 Networks

The Inventory and Monitoring Program is a national effort that is divided geographically and ecologically into many networks. This approach is needed not only for funding allocation and to attend to nationwide park management concerns, but also to ensure that, at the network level, high-priority local management concerns are addressed as effectively as national ones. It will be critical for the Arctic Network to work closely with other networks to ensure that monitoring products integrate well at the national level, and that cross-network comparisons are valid and responsive to management needs. There are numerous databases, information resources, templates, and examples from preceding networks that are available through the national and regional offices that will be of great value in guiding the development of the Arctic Network. We expect to use the expertise and learning experiences of the national and regional offices and the other four networks in Alaska as our program matures.

Park-Specific Legislative Mandates

All of the NPS units within the ARCN parks are relatively recent additions to the National Park System. Bering Land Bridge National Preserve was established by the Alaska National Interest Lands Conservation Act on December 2, 1980. Section 202 (2) states:

> *Bering Land Bridge National Preserve shall be managed for the following purposes, among others: To protect and interpret examples of arctic plant communities, volcanic lava flows, ash explosions, coastal formations, and other geologic processes; to protect habitat for internationally significant populations of migratory birds; to provide for archeological and paleontological study, in cooperation with Native Alaskans, of the process of plant and animal migration, including man, between North America and the Asian Continent; to protect habitat for, and populations of, fish and wildlife including, but not limited to, marine mammals, brown/grizzly bears, moose, and wolves; subject to such reasonable regulations as the Secretary may prescribe, to continue reindeer grazing use, including necessary facilities and equipment, within the areas which on January 1, 1976, were subject to reindeer grazing permits, in accordance with sound range management practices; to protect the viability of subsistence resources; and in a manner consistent with the foregoing, to provide for outdoor recreation and environmental education activities including public access for recreational purposes to the Serpentine Hot Springs area. The Secretary shall permit the continuation of customary patterns and modes of travel during periods of adequate snow cover within a one-hundred-foot right-of-way along either side of an existing route from Deering to the Taylor Highway, subject to such reasonable regulations as the Secretary may promulgate to assure that such travel is consistent with the foregoing purposes.*

Cape Krusenstern National Monument was established in 1978 by presidential proclamation and then designated in 1980 by ANILCA(16 USC 3101). Section 201(3) of ANILCA specifies that:

> *The monument shall be managed for the following purposes, among others: To protect and interpret a series of archeological sites depicting every known cultural period in arctic Alaska; to provide for scientific study of the process of human population of the area from the Asian Continent; in cooperation with Native Alaskans, to preserve and interpret evidence of prehistoric and historic Native cultures; to protect habitat for seals and other marine mammals; to protect habitat for and populations of birds and other wildlife and fish resources; and to protect the viability of subsistence resources. Subsistence uses by local residents shall be permitted in the monument in accordance with the provisions of Title VIII [of ANILCA].*

Gates of the Arctic Park and Preserve was also established by ANILCA. Section 201(4)(a) directs that:

> *The park and preserve shall be managed for the following purposes, among others: To maintain the wild and undeveloped character of the area, including opportunities for visitors to experience solitude, and natural environmental integrity and scenic beauty of the mountains, forelands, rivers, lakes, and other natural features; to provide continued opportunities, including reasonable access, for mountain climbing, mountaineering, and other wilderness recreational activities; and to protect habitat for and the populations of, fish and wildlife, including, but not limited to, caribou, grizzly bears, Dall's sheep, moose, wolves, and raptorial birds. Subsistence uses by local residents shall be permitted in the park, where such uses are traditional, in accordance with the provisions of title VIII.*

Kobuk Valley National Park was established by ANILCA. Section 201(6) of this act states:

> *Kobuk Valley National Park shall be managed for the following purposes, among others: To maintain the environmental integrity of the natural features of the Kobuk River Valley, including the Kobuk, Salmon, and other rivers, the boreal forest, and the Great Kobuk Sand Dunes, in an undeveloped state; to protect and interpret, in cooperation with Native Alaskans, archeological sites associated with Native cultures; to protect migration routes for the Arctic caribou herd; to protect habitat for, and populations of, fish and wildlife including but not limited to caribou, moose, black and grizzly bears, wolves, and waterfowl; and to protect the viability of subsistence resources. Subsistence uses by local residents shall be permitted in the park in accordance with the provisions of title VIII. Except at such times when, and locations where, to do so would be inconsistent with the purposes of the park, the Secretary shall permit aircraft to continue to land at sites in the upper Salmon River watershed.*

Noatak National Monument was created by presidential proclamation in December 1978. On December 2, 1980, through the enactment of ANILCA, the monument became Noatak National Preserve. Section 201(8) of ANILCA specifies that:

> *The preserve shall be managed for the following purposes, among others: To maintain the environmental integrity of the Noatak River and adjacent uplands within the preserve in such a manner as to assure the continuation of geological and biological processes unimpaired by adverse human activity; to protect habitat for, and populations of, fish and wildlife, including but not limited*

to caribou, grizzly bears, Dall's sheep, moose, wolves, and for waterfowl, raptors, and other species of birds; to protect archeological resources; and in a manner consistent with the foregoing, to provide opportunities for scientific research. The Secretary may establish a board consisting of scientists and other experts in the field of arctic research in order to assist him in the encouragement and administration of research efforts within the preserve.

Overview of ARCN Ecosystems

The ARCN parks contain a broad array of the ecosystems typical of the subarctic (boreal forest or taiga), and arctic (tundra) biomes of northwestern North America. The boundary, or ecotone, between these two biomes is also represented in many different phases. Because these parks encompass large areas of mountainous terrain, including a major portion of the Brooks Range, they also include examples of virtually every type of alpine situation to be found in northern Alaska.

The nature of boreal and arctic ecosystems is often profoundly influenced by climate, especially whether and to what degree the climate is maritime or continental. The climate of the ARCN parks varies from the extreme continentality of interior Alaska to the more maritime coastal areas of the parks bordering the Chukchi Sea. However, this maritime climate is somewhat modified by the presence of pack ice, which minimizes the moderating effect of the sea during the six to nine months it is present. Thus winters, even in coastal areas, are intensely cold and have relatively moderate precipitation and snow cover.

The total area encompassed by the five parks that make up the ARCN is roughly 7,802,305 hectares (19.3 million acres), of which: Bering Land Bridge National Preserve is 1,026,930 hectares (2,537,592 acres); Cape Krusenstern National Monument is 236,448 hectares (584,276 acres); Gates of the Arctic Park and Preserve is 3,323,270 hectares (8,211,974 acres); Kobuk Valley National Park is 675,747 hectares (1,669,808 acres); and the Noatak National Preserve is 2,539,910 hectares (6,276,255 acres).

Climate

The climate of northwest Alaska is characterized by long, cold winters and cool wet summers. The entire region receives continuous sunlight during the summer for at least 30 days. While the coastal area experiences a predominantly maritime climate, the interior area has a more continental climate, with greater seasonal variations in temperatures and precipitation. Mean summer temperatures for the northwest region range from ~ 0° C in the higher mountains to as high as 12° C in the Mission Lowlands. Mean winter temperatures for the region range between –17 and –28° C.

The coastal areas typically receive regular high winds. Mean monthly winds at Kotzebue are above 10 knots from September through April and blow from the east. Mean wind speeds are comparable during the summer months (average 10.5 knots) but are from the west. August and September are the windiest months, while the most extreme winds are associated with winter storms. Wind speeds are somewhat less in the interior than at the coast. Coastal and lower elevation areas in the southwest portion of the region receive approximately 25 cm of precipitation annually. Higher inland areas to the east receive 63 to 76 cm of moisture. Rainfall usually increases as the summer months progress, usually peaking in August. Annual snowfall ranges from 114 cm in the southwest to more than 250 cm at higher elevations in the east. Freeze-up of surface waters generally occurs from early to mid October, and breakup occurs in mid to late May.

The climate of the Seward Peninsula and Bering Land Bridge National Preserve shows both maritime and continental influences. When surrounding marine waters are ice-free (mid June to early November), temperatures are moderate, humidity is high, and skies are typically cloudy, especially near the coast. Interior sections, even during this summer period, are somewhat drier and less cloudy and therefore have greater heat buildup during daytime hours and a greater daily temperature change. Summer is the wettest period, with perhaps 7 to 10 cm of the 25 cm of annual precipitation being recorded. Snow, with a relatively low water content, averages about 127 to 152 cm per year.

Geology

The national parks, preserves and monuments of the Arctic Network contain several very general components including (a) most of the western half of Alaska's Brooks Range mountains, (b) both hilly and low terrain on the northern Seward Peninsula, (c) broad lowlands draining major river systems approaching the coast of the Chukchi Sea, and (d) coastal lowlands and bluffs. Collectively, the processes responsible for the landforms, bedrock, and soils within ARCN are a complex suite spanning all three geologic eras, from the late Paleozoic to the present. Maritime, lacustrine, palustrine, lotic, aeolian, glacial, and volcanic/tectonic processes have all left prominent evidence of their influence throughout the ARCN region, with many interesting and often unique subtexts within each park unit.

Formation of major bedrock components spans much of earth's geologic history. The southern flank of the Brooks Range includes sedimentary rock dating to the late Precambrian Era, while the volcanic deposits on the Seward Peninsula date to as recently as 1,000 years ago. The Brooks Range itself is a collection of sub-ranges with igneous, sedimentary, and metamorphosed rocks added at different times, often through tectonic movement bringing terranes from distant origins. Different episodes of uplift, deformation, and intrusion have arranged the geologic substrata into several major synclines and anticlines with complex patterns of folding, fracturing, and thrust blocks. A comprehensive description of Brooks Range geology is a large report unto itself, but several noteworthy examples help to illustrate its essential character.

Much of the central Brooks Range is dominated by sedimentary deposits of Upper and Middle Devonian origin. These include limestone, sandstone, shale, siltstone, with occurrences of conglomerates, chert and metamorphosed deposits. Notable formations include the Hunt Fork Shale, the Kanayut Conglomerate, the Eli Limestone, and the Nanook Limestone. This wide band of Devonian deposits stretches from the eastern border of Gates of the Arctic National Park and Preserve through the central portion of the Noatak National Monument. Small but very prominent intrusive formations of early Cretaceous origin also occur within this area. The steep, jagged, and renowned Arrigetch Peaks are part of a granitic intrusion separating the Noatak and Alatna drainages within Gates of the Arctic.

Cape Krusenstern National Monument and the western edge of the Noatak NP are dominated by similar sedimentary deposits of older Devonian and Silurian origin. Limestone, dolomite, phyllite and chert are common components. Smaller pockets of these strata also occur within the Central Brooks Range. Notable formations include the Skajit Limestone.

The southern flank of the Brooks Range contains a collection of early Paleozoic and Precambrian deposits, including limestones, sandstones and shales along with siliceous and calcareous schists. This narrow band stretches from Kobuk Valley National Park east through the southern portions of Noatak National Park and Gates of the Arctic.

South of the Brooks Range in Kobuk Valley National Park, early and late Cretaceous sedimentary deposits underly later glacial and fluvial sediments in the broad Kobuk Valley. Shale, sandstone, siltstone, conglomerate, and greywacke dominate these deposits.

Geologic deposits in the uplands of Bering Land Bridge National Preserve are dominated by recent volcanic lava and ash flows dating from the Cretaceous-Tertiary boundary to the late Quaternary Period. Distinct lava flows around Imuruk Lake range in age from 65 million years (the Tertiary Kugruk volcanics) to as recently as 1,000 years (the Lost Jim flow). Older flows occurred on many separate occasions from a variety of vents and are now largely buried by the more recent flows as well as by wind-blown deposits of silt. Exposed volcanic rocks, all dark basaltic material, were originally rather smooth *pahoehoe* flows, with older flows subject to severe shattering by frost action into large angular fragments. Notable Cretaceous granitic intrusions also occur within these formations, with the tors surrounding Serpentine Hot Springs being the best known example.

Landforms and Soils

Landforms and soils within Arctic Network units are mainly products of glacial, fluvial, and Aeolian processes during the Cenozoic Era. Late Pleistocene glaciation exerts the most prominent, lasting influence throughout the region, having reshaped mountains formed by prior uplift, scoured broad valleys, and deposited boulder-to-silt-sized sediments through a variety of processes.

Higher peaks of Brooks Range mountains in GAAR are characterized by steep spires flanked by cirques and sharp arêtes as Pleistocene glaciers carved and transported bedrock downslope. Remnant ice left some higher areas dotted with depressions, creating small kettle lakes, while major glaciers gouged typical, broad, U-shaped valleys in what are now all of the major river drainages within ARCN. Many smaller mountains to the south and west through the Noatak National Park and Kobuk National Park were overtopped by ice sheets and have a rounded or domelike profile with smooth saddles between peaks.

A suite of glacial deposits commonly line toe slopes and valley bottoms in the Brooks Range and its foothills. Kame terraces, recessional and lateral moraines, eskers, and outwash deposits are scattered throughout the region. Aeolian sand and silt deposits also occur intermingled with other features. Of particular interest are the dune features in Kobuk National Park. Mostly formed during the previous Pleistocene interglacial and covering an area of roughly 90,000 ha, they are now primarily vegetated, with the exception of the Great Kobuk, Little Kobuk, and Hunt River dunes, which are still active and cover about 8,300 ha.

Post-glacial processes continue to modify the landscape as seasonal snow, ice, water, and wind continue to weather, transport, and redeposit substrates. Higher elevations typically grade from bedrock to fell fields and then talus moving downslope. Valley bottoms consist of fine sediments, sand, and gravel, redistributed as sinuous river systems carve new channels and abandon old ones. Mass wasting features are common on many hillslopes, some of which have been attributed to solifluction and gelifluction, possibly caused by intense summer rainfall events. Melting permafrost in the form of thermokarst and thaw lakes occurs in pockets in ARCN and may be caused by a combination of natural climatic and disturbance events.

Bering Land Bridge National Park and Cape Krusenstern National Monument are subject to coastal processes as well. Post-glacial isostatic rebounding and subsequent tidal forces shape much of the coast, leading to long rocky and gravelly bluffs and beach ridges. Cape Krusenstern is particularly known for the beach ridges made famous by the work of J. Louis Giddings, who described a chronosequence of prehistoric beach habitation in *The Archaeology of Cape Krusenstern*.

Large lagoon systems make up much of the rest of the coast, along with a few prominent river deltas such as the mouth of the Noatak River.

The north coast of the Seward Peninsula in Bering Land Bridge National Park is comprised of marine deposits from the late Pleistocene and Holocene epochs. Most of these sediments originate from the south and west coast of the Seward Peninsula and are transported by prevailing currents in a continuing, progressive process of coastal erosion and redeposition that includes a highly dynamic series of low barrier islands.

Permafrost underlies much of the terrain within the Arctic Network, sometimes within 10 cm of the surface. Pingos, ice wedges, patterned ground, thaw ponds, well-developed tussocks, and cryoturbation may be found primarily in and near valley bottoms throughout the region. Higher elevations and steeper slopes may or may not contain permafrost as frozen water by virtue of aspect (through summer insolation), grain size, drainage, and disturbance regime. Small snow fields and several small glaciers still exist within the region, primarily at higher elevations on north-facing slopes within Gates of the Arctic.

Soils within the Arctic Network are diverse and range from thin layers of coarse-grained material to loamy, fine grained and organic deposits. Heavily vegetated areas usually contain a substantial layer of peat and semi-decomposed organics atop frozen silt and gravel layers. Lowlands with a high density of lakes, estuaries, and freshwater wetlands, common in the western units, have deeper layers of fine-grained organic soils. Higher elevations are most commonly talus and sandy gravel, either exposed or covered by a thin layer of alpine tundra vegetation. Glacial and fluvial deposits near flowing water contain a mixture of grain sizes and are continually reorganized through hydrologic processes on streams and rivers.

Freshwater Resources of the Arctic Network

The ARCN parks have an extensive and diverse array of freshwater ecosystems that are relatively undisturbed by human activity. Key features of the landscape are the large freshwater lakes, seemingly endless miles of river networks, large expanses of wetlands, and unique isolated spring systems. There are seven wild and scenic rivers in the ARCN, including the Noatak, Salmon, Kobuk, Alatna, John, Tinayguk, and North Fork of the Koyukuk. All of the rivers of the ARCN are free-flowing and run clear most of the year. There are a few glacial streams that originate in the Brooks Range and several spring streams, including tributaries of the Reed River, Kugrak River, and Alatna River, although to date few studies have been conducted on them.

Much of the land within the ARCN is drained by streams that flow from the uplands into lowland areas, then empty into the Chukchi Sea or coastal lagoons. These lagoons have been a primary fishing ground for

Native populations for the past 9,000 years. During the ice-free season, some of these streams and associated coastal lagoons provide important habitat for anadromous and freshwater fish populations, birds, and terrestrial mammals.

There are many lakes in the ARCN. Many of the large deep lakes such as Chandler, Selby, Feniak, and Matcharak are renowned for their fisheries resources. These sites are heavily used by both subsistence and sport fishers. One of the largest, Walker Lake, was designated a national natural landmark in April 1968. Thousands of shallow lakes and wetlands are distributed throughout the parks. These ecosystems have diverse geologic origin, including countless thaw ponds, kettle lakes, maars, and oxbows that provide important rearing areas for fish, macroinvertebrates, and waterfowl.

There is little information on ground water in these parks, although some larger geothermal systems have been studied (e.g., Serpentine Hot Springs).

Freshwater Resources of the Bering Land Bridge National Preserve

Further study and classification of the freshwater resources within Bering Land Bridge National Preserve is needed. Two of the largest ecologically significant landscape features in BELA are Ikpek and Cowpack lagoons. These lagoons and the drainages that surround them are part of an important migratory shorebird and waterfowl resting and feeding area. The rivers and lagoons along this stretch of coast provide the only extensive system of barrier islands and sheltered water between the Arctic Ocean and the Yukon River delta. Consequently, migrating shorebirds and waterfowl use it extensively.

Extensive surface water is present in the northern half of the preserve, but the actual annual hydrologic budget is relatively small owing to the modest precipitation (25 to 38 cm). Five major rivers have substantial drainage basins within the boundary of the preserve, including the Serpentine, Cowpack, Nugnugaluktuk, Goodhope, and Noxapaga rivers. Others have only a small portion within or along the boundaries of the preserve. These include the Inmachuk, Kugruk, Koyuk, and Kuzitrin.

Serpentine Hot Springs is the main geothermal resource in the park. There are four areas along a 0.8 km reach of Hot Springs Creek where hot water discharge is visible. Discharge at the upper hot spring area (the location of the wooden bath area) is approximately 106 L/s, with average temperatures ranging from 61 to 72°C (Roeder and Graham 1979). Discharge at the lower portion of the spring area is 146 L/s. The surface water temperature has been measured at 15 to 21°C. There are also several small springs at Pilgrim Springs.

There is little basic information about fish diversity and distribution within BELA. The Alaska Natural Heritage Program identified 25 freshwater species with 9 documented. Information on fish presence in BELA appears to come mainly from reconnaissance-type trips to specific locations or from incidental observations by biologists working on other taxa. While there has been considerable work on freshwater and marine/coastal fish in the region by the Alaska Department of Fish and Game and others, very little of that work has occurred within the bounds of preserve.

Freshwater Resources in Cape Krusenstern National Monument

The lands within CAKR are drained by a number of streams that flow from the uplands and empty into the Chukchi Sea or coastal lagoons. During the ice-free season, some of these streams and associated coastal lagoons provide important habitat for anadromous and freshwater fish populations, birds, and terrestrial mammals. During the winter, stream flow at the surface ceases as waters freeze. In areas where substantial springs exist, water may continue to flow out at the surface and then freeze into successive thin sheets of ice, forming aufeis areas. Both Jade and Rabbit creeks are subject to aufeis formation and have numerous channels and low intervening gravel bars.

Most of the streams in the monument are clearwater streams, exhibiting low levels of suspended solids, turbidity, and nutrients. Water is highly oxygenated, moderately hard to hard, and of the calcium bicarbonate type. At the Red Dog Mine site outside the monument, waters are naturally contaminated with cadmium, lead, and zinc. This contamination occurs because the ore in the ground is of sufficient quantity and concentration to alter the water as it passes over the ore deposit. There are several large lagoons and a few small lakes located within the monument. Ground water information for the monument is currently very scarce.

The Alaska Natural Heritage Program expected species list for freshwater and anadromous fish in the monument includes 24 species, 18 of which have been documented. Their list of marine fish includes 38 species, with only 8 species documented. Of primary importance to subsistence users are whitefish, including humpback whitefish (*Coregonus pidschian*), least cisco (*Coregonus sardinella*), Bering cisco (*Coregonus laurettae*), and broad whitefish (*Coregonus nasus*).

Arctic char spawn in Rabbit, Jade, and Kilikmak creeks and in the Situkuyok River. Arctic grayling (*Thymallus arcticus*) overwinter in the Rabbit Creek drainage and in the streams draining the Igichuk Hills. Spawning pink (humpy) salmon (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta)* are found in the Wulik and Noatak Rivers, as are king (chinook) salmon (*Oncorhynchus tshawytscha*) and red (sockeye) salmon (*Oncorhynchus nerka*). Both chum and pink salmon most likely occur in Rabbit Creek. Northern pike (*Esox lucius*) are present in many streams in the monument south of Krusenstern Lagoon and east to Sheshalik Spit. Occasionally burbot (*Lota lota*) are found in the same areas (ADF&G 1978). Dolly Varden (*Salvelinus malma*) are known to spawn in Rabbit Creek. Herring (*Clupea* spp.) spawn in Krusenstern Lagoon and in the shallow coastal waters north of Sheshalik Spit, where sheefish (*Stendous leucichthys*) also overwinter.

Freshwater Resources in Gate of the Arctic Park and Preserve

Tributaries of four major river systems originate in GAAR. To the north the Nigu, Killik, Chandler, Anaktuvuk, and Itkillik rivers drain to the Colville River. The Noatak River flows west and the Kobuk River southwest, both from headwaters in the western part of the park. The Reed and the Noatak rivers both start as glacial runoff from the flanks of Mount Igikpak. The John, Alatna, and North Fork of the Koyukuk rivers drain south to the Yukon River. Headwaters of six of the seven rivers that are designated as "Wild and Scenic" in ARCN are located in GAAR, including the Alatna, John, Kobuk, Noatak, North Fork of the Koyukuk, and Tinayguk rivers.

At least three "warm" springs are located within the park and preserve. The Reed River spring is located near the headwaters of the Reed and had a measured water temperature of 50°C at the warmest pool (NPS 1982). Spring sources are also located on the lower Kugrak and Alatna rivers.

The expected species list for the fishes of GAAR developed by the Alaska Natural Heritage Program includes 16 species, of which 14 have been documented. The most common fish species include arctic grayling (*Thymallus arcticus*), lake trout (*Salvelinus namaycush*), northern pike (*Esox lucius*), arctic char (*Salvelinus alpinus*), whitefish (*Coregonus* spp.), sheefish (*Stenodus leucichthys*), salmon (*Oncorhynchus* spp.), long-nosed sucker (*Catostomus catostomus*), burbot (*Lota lota*), nine-spined stickleback (*Pungitius pungitius*), and slimy sculpin (C*ottus cognatus*).

The Kobuk and Koyukuk rivers are major chum salmon spawning streams. Sheefish also spawn in the Kobuk. These fish, along with whitefish, are the most important subsistence fishes. Some lake trout and arctic char are also taken from lakes for subsistence use. Recreational fishing is primarily for arctic grayling, arctic char, sheefish, and lake trout.

Freshwater Resources of Kobuk Valley National Park

The Kobuk and Noatak rivers are the largest rivers in northwest Alaska and together drain an area of 63,654 km^2. The Kobuk River drains 31,028 km^2 and has an estimated annual average flow of 438 m^3 per second. The river is 558 km long and 0.30 to 0.45 km wide in its lower and middle reaches. It is clear, except at the highest water stage, and has a generally sandy or gravelly bottom. The river is 50 m above sea level at the eastern boundary of Kobuk Valley National Park. Meander scrolls, oxbow bends, and sloughs are abundant along the river's course. The floodplain of the Kobuk River varies from 1.6 to 12.8 km wide.

The major tributaries of the Kobuk River within the park boundary are the Kallarichuk, Salmon, Tutuksuk, Kaliguricheark, Hunt, and Akillik rivers. All have their headwaters in the Baird Mountains, and all are entirely undeveloped. The Salmon River and its surrounding watershed is 1,709 km and is a designated Wild and Scenic River. The Tutuksuk, east of the Salmon River, is 48 km long and drains 906 km^2. The Hunt River, in the eastern portion of the park, is 64 km long and drains 1,592 km^2.

Numerous small lakes and ponds lie in the Kobuk watershed, particularly in the lowlands along the river. Some ponds and lakes formed as detached oxbows of the meandering river, while others are thaw ponds, formed where permafrost has melted and caused depressions. Some small lakes of indeterminate origin lie on the north slopes of the Waring Mountains, and some true cirque lakes are found in the Baird Mountains.

Total dissolved solids in most streams in the region are generally less than 200 mg per liter. The Kobuk River at Kiana contains less than 250 mg per liter of dissolved solids. Magnesium and bicarbonate are most prevalent, while calcium and chloride are found in smaller quantities. Sediment loads are comparatively low; the free-flowing waters of northwest Alaska generally have the lowest yield of sediment in the state, due largely to low topographic relief, lack of glaciers, low levels of runoff, and the stabilizing effect of permafrost on soils.

The expected fish species list developed by the Alaska Natural Heritage Program includes 22 expected species, with 16 species documented. A review of the available literature suggests that fish in KOVA are less well known than in NOAT. Most of the work has been conducted by the Alaska Department of Fish and Game relative to commercial and subsistence fisheries. The pre-ANILCA expedition of Melchior (1976) included some fish inventory work in KOVA.

Although all five species of Pacific salmon occur in the waters of the region, only chum (*Oncorhynchus keta*), king (*Oncorhynchus tshawytscha*), and pink (*Oncorhynchus gorbuscha*) salmon occur in the drainages of Kobuk Valley National Park. Chum salmon is the most abundant species of salmon in the region and is the most significant species for commercial and subsistence fisheries. The Salmon and Tutuksuk rivers are major spawning and production tributaries of the Kobuk River for chum salmon. Arctic grayling (*Thymallus arcticus*) and arctic char (*Salvelinus alpinus*) are distributed throughout the waters of the park. *Inconnu*, or sheefish (*Stenodus leucichthys*), inhabit the Kobuk and Selawik rivers. Sheefish overwinter in Hotham Inlet and Selawik Lake. After ice breakup, sheefish move upriver to spawning areas. Known spawning areas are located upriver from the village of Kobuk. Northern pike (*Esox lucius*), whitefish (*Coregonus* spp.), burbot (*Lota lota*), long-nosed sucker (*Catostomus catostomus*), slimy sculpin (*Cottus cognatus*), and least ciscos (*Coregonus sardinella*) inhabit most rivers and lakes in the region, including those of the park.

Freshwater Ecosystems within the Noatak National Preserve

The Noatak National Preserve was, in part, created to maintain the environmental integrity of the Noatak River and adjacent uplands within the preserve to assure the continuation of geological and biological processes unimpaired by adverse human activity. The Noatak River and its surrounding watershed (3,035,200 ha) is also an internationally recognized Biosphere Reserve (UNESCO). The Noatak is the 11th largest river in Alaska in terms of the area it drains. Before flowing into Hotham Inlet of Kotzebue Sound, the river drains 32,600 km^2 and has an average annual flow of 309 m^3 per second. The main artery of the Noatak is 700 km long. Eleven relatively large streams, from 50 to 160 km long, are tributaries to the Noatak, as are 37 smaller streams. The Noatak River is a designated Wild and Scenic River.

Many lakes are within the Noatak watershed. Feniak Lake is the largest within the preserve boundary. Countless thaw ponds and potholes occur throughout the area, most as a result of permafrost that impedes the downward percolation of water that collects in depressions and thermokarst erosion, boosted by permafrost melting. Other ponds and lakes were formed as detached oxbows of the meandering river or developed as part of the extensive flat delta at the mouth of the Noatak River. Lake waters are generally lower in dissolved solids than river waters. Lowland surface waters, such as tundra lakes, however, are often characterized by a brownish color and are generally high in organic material.

Approximately 22 species of fish are found within the Noatak drainage. Arctic grayling (*Thymallus arcticus*) and arctic char (*Salvelinus alpinus*) are the most common sport fish. Both spawn on sandy gravel substrate shortly after breakup in the Noatak and its tributaries. Most char are anadromous and are found in the Noatak River and its tributaries upriver as far as the Kugrak River. Chum salmon (*Oncorhynchus keta*) are found throughout the Noatak drainage; sockeye (*Oncorhynchus nerka*), coho (*Oncorhynchus kisutch*), king (*Oncorhynchus tshawytscha*), and pink (*Oncorhynchus gorbuscha*) salmon are also present, but in fewer numbers and are confined to the lower reaches of the Noatak River. *Inconnu*, or sheefish (*Stenodus leucichthys*), inhabit the lower Noatak River.

Lake trout (*Salvelinus namaycush*) are found in some larger and deeper lakes (Feniak, Desperation, Kikitutiorak, and Narvakrak). Burbot

(*Lota lota*), or freshwater cod, also inhabit deep lakes and large streams. Northern pike (*Esox lucius*), whitefish (*Coregonus* spp.), and least ciscos (*Coregonus sardinella*) inhabit rivers and lakes in the region. The long-nosed sucker (*Catostomus catostomus*) is found in rivers, streams, and lakes in the Noatak drainage and is occasionally dried or smoked for eating. The slimy sculpin (*Cottus cognatus*) and the nine-spined stickleback (*Pungitius pungitius*) are common prey fish. Blackfish (*Dallia pectoralis*) inhabit lowland ponds in the lower Noatak.

Coastal Ecosystems of ARCN

Coastal ecosystems are a dominant feature within the Arctic Network. Of the approximately 370 km (230 miles) of shoreline in ARCN, 120 km (75 miles) are in Cape Krusenstern National Monument and 250 km (155 miles) are in Bering Land Bridge National Preserve. The total shoreline, including bay and barrier island ecosystems surrounded by BELA, reaches approximately 450 km (280 miles). Together these parks make up the third largest block of coastline that the National Park Service manages (Figure 8).

The coastal areas of ARCN have an extensive and diverse array of coastal ecosystems, which are relatively undisturbed by human activity. BELA and CAKR shorelines directly abut the Kotzebue Sound, Chukchi Sea, and Bering Strait; however, neither park includes the marine waters offshore, since NPS boundaries end at the mean high tide mark. Important coastal ecosystems within CAKR and BELA include lagoons, estuaries, and islands as well as potential denning sites, seal haul-outs, and bird nesting and migratory stopover sites important for the marine mammals and birds of the adjacent coastal waters. In addition, both BELA and CAKR have explicit mandates in their establishing legislation for the protection of marine mammal habitat. The U.S. Fish and Wildlife Service (polar bears and walrus) and the National Marine Fisheries Service (seals and whales) oversee management of most marine mammal species in and around these coastal waters.

Nearshore coastal waters and shoreline ecosystems of importance to the Arctic Network include intertidal and subtidal zones, salt-dominanted inlet systems, sandy shores, rocky cliffs, dune systems, and islands. Nearshore coastal waters have varying degrees of wave action and currents. Due to the almost constant exposure to wind and tidal currents, these ecological habitats are often more turbulent than lagoons or estuaries. Lagoon and estuarine ecosystems are common along the ARCN coastline. In fact, much of the land within the ARCN is drained by streams that flow from upland into lowland areas, then empty into the Chukchi Sea or coastal lagoons. There are five large coastal lagoons in CAKR, including Imak, Kotlik, Krusenstern, Ipiavik, and Akukulak lagoons. There are two large lagoons located in BELA: Ikpek and Cowpack. Several of these lagoons have been a primary fishing ground for Native

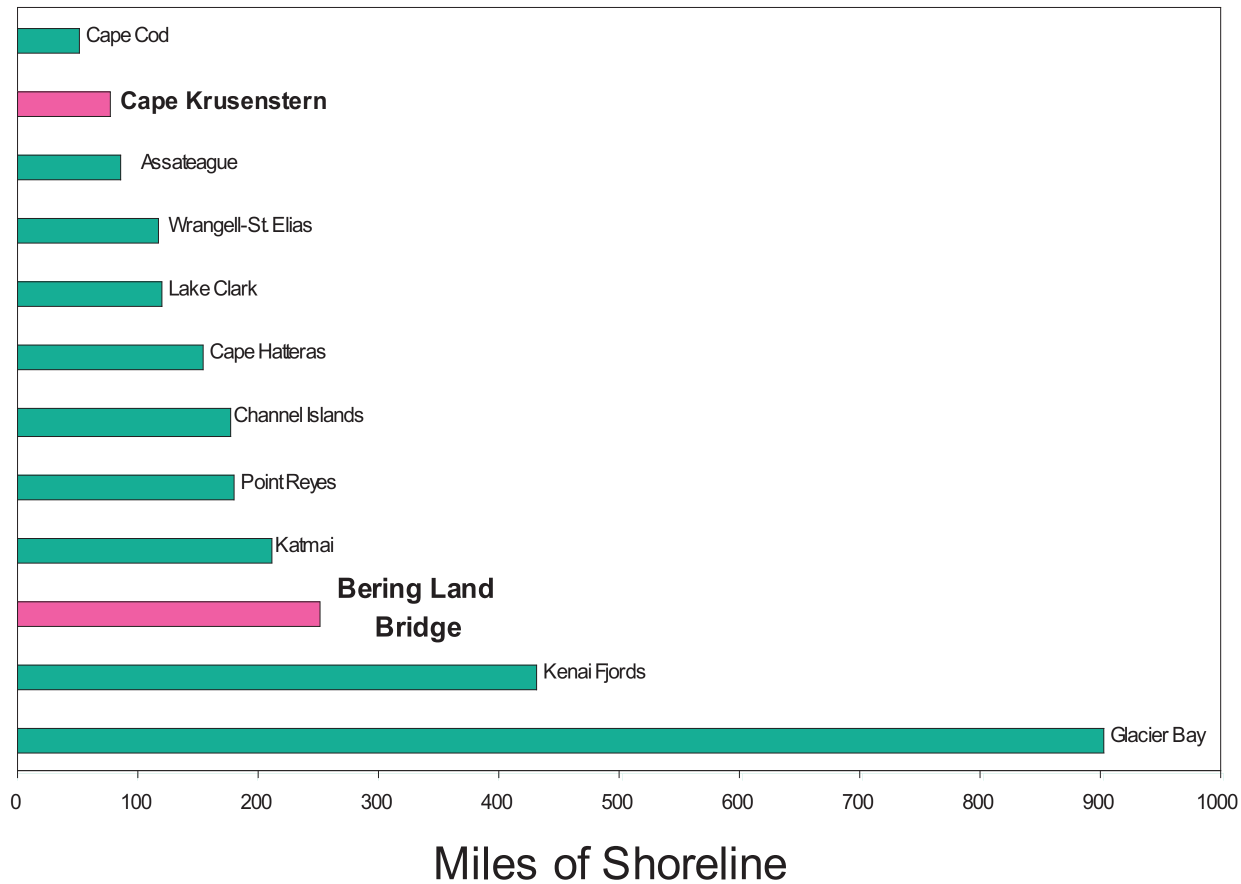


Figure 8: Miles of shoreline in ARCN in comparison to other NPS lands with coastal areas.

populations for the past 9,000 years. During the ice-free season, some of these streams and associated coastal lagoons provide important habitat for anadromous and freshwater fish populations, birds, and terrestrial mammals.

Eelgrass beds (*Zostera marina* L.) have been documented as far north as Cape Espenberg in BELA (McRoy 1968), and incidental observations of eelgrass in CAKR have been officially noted over the last decade (McRoy, pers. comm.). These seagrass beds are primary habitat for many species of primary consumers (e.g., zooplankton) and fishes. The fauna of seagrass beds is often richer than areas not dominated by these habitats, due to the enhanced habitat and energy created by the presence of these beds.

The lagoons between Cape Krusenstern and Sheshalik are heavily used by migrating waterfowl. It is an important fall staging area for thousands of geese, ducks, shorebirds, and gulls (USFWS 1984). Seabird colonies are present in CAKR on Noatak Island (aleutian terns), at the Uhl-Williams site (aleutian and arctic terns), Krusenstern Lagoon (arctic terns and glaucus gulls), Kasik Lagoon (glaucus and mew gulls), and Tasaychek Lagoon (arctic and aleutian terns). In BELA, seabird colonies are located on the

Sullivan Bluffs (glaucus gulls, black legged kittiwakes, and murres) and on two un-named islands off the coast of Kongealoruk Creek (glaucus gulls) (Alaska Department of Fish and Game 1978). This area is also important for subsistence hunting of waterfowl and egg gathering.

Approximately 18 species of marine mammals use the waters of the Chukchi Sea and Kotzebue Sound, adjacent to CAKR and BELA (Table 1). Important marine mammal habitat within the park boundaries includes seal haul-out areas on the beaches of Cape Espenberg and the small islands southeast of Cape Espenberg.

Table 1. Marine mammal species present in the ocean adjacent to Bering Land Bridge National Preserve and Cape Krusenstern National Monument.

Scientific Name	Common Name
Odobenus rosmarus	walrus
Eumetopias jubatus	Stellar's sea lion
Callorhinus ursinus	northern fur seal
Erignathus barbatus	bearded seal
Phoca fasciata	ribbon seal
Phoca hispida	ringed seal
Phoca largha	spotted seal
Phoca vitulina	harbor seal
Phocoena phocoena	harbor porpoise
Ursus maritimus	polar bear
Balaena glacialis	right whale
Balaena mysticetus	bowhead whale
Balaenoptera acutorostrata	minke whale
Balaenoptera physalus	fin whale
Orcinus orca	killer whale
Eschrichtius robustus	gray whale
Delphinapterus leucas	beluga
Monodon monoceros	narwhale

Marine mammals are an important element in the subsistence lifestyle of many villages surrounding the park units; not only villages directly on the coast (such as Wales, Shishmaref, Kivalina, and Deering), but for inland villages as well (e.g., Noatak, Noorvik, Ambler, and Shungnak). Walrus (*Odobenus rosmarus*), bowhead whale (*Balaena mysticetus*), and bearded (*Erignathus barbatus*), ringed (*Phoca hispida*), and spotted seals (*Phoca largha*) are taken most often, but other whales, including beluga (*Delphinapterus leucas*), and seals are also found offshore. Although many of the harvested marine mammals do not actually spend much (or in some cases no) time on NPS lands, there are hunting camps and transportation routes within the parklands that are used in the traditional taking of these and other marine species. The harvest of all species of marine mammals is controlled under the Marine Mammals Protection Act of 1972, which provides for subsistence harvest by Native Alaskans but forbids recreational hunting.

The ringed seal (*Phoca hispida*), the smallest of the northern seals, averages 70 kg and is found in the greatest densities off Cape Krusenstern in June. This seal is a life-sustaining species for people in the region, providing skin, meat, and oil. Traditional hunting of this species is concentrated off the coast of Cape Krusenstern at "Sealing Point." Bearded seals (*Erignathus barbatus*), the largest of the western arctic seals, weigh up to 360 kg. They are widely distributed in the Chukchi and Bering seas, where they feed on shrimp, benthic fish, clams, and worms. They appear in June in the waters adjacent to the monument. Despite the bearded seals' short seasonal presence, it is a highly important subsistence resource. Spotted seals (*Phoca largha*) and ribbon seals (*Phoca fasciata*) are also found off Cape Krusenstern. The spotted seal weighs up to 135 kg and feeds on herring (*Clupea pallasi*), salmon (*Oncorhynchus* spp.), and whitefish (*Coregonus* spp.) along the coast of the Chukchi Sea. The animals concentrate generally along the southern extent of ice pack. The ribbon seal (*Phoca fasciata*), with its distinctive white bands against a black body, is found in greatest abundance south and east of the Seward Peninsula in the central Bering Sea.

Walrus (*Odobenus rosmarus*), are uncommon off Cape Krusenstern, although stray animals and carcasses washed ashore are taken for their ivory, blubber, and meat, if usable.

Polar bears (*Ursus maritimus*) are found along the Chukchi Sea coast in winter, where they move into the area with the pack ice. Polar bears have been documented within the boundaries of BELA. These bears are thought to move with pack ice between Russia and the U.S.

Beluga whales (*Delphinapterus leucas*), which are small whales about 5 m long, occur throughout the Chukchi and Bering seas. These white whales travel in groups and are prized by subsistence hunters for their edible skin, blubber, and meat. A few beluga are taken from year to year along the monument's coastline when the shoreline becomes ice free or when they appear in open leads in the ice during sealing season (Uhl and Uhl 1980). Bowhead, gray, and finback whales have been observed within the waters of the Chukchi Sea off Cape Krusenstern.

Terrestrial Ecosystems of the Arctic Network

Terrestrial Vegetation

The most conspicuous feature of the vegetation in northwestern Alaska is treeline, or northward or coastward limit of conifer forests. The forest reaches its northwesternmost limit in North America in the vicinity of the eastern border of Cape Krusenstern and the western edge of the Noatak Preserve (Young 1974) but treeline forms a complex and convoluted boundary through much of the three more eastern parks. A number of other organisms have ranges strongly associated with the presence of conifers: red squirrels, porcupines, certain typically understory plants, some tree-nesting birds, and some epiphytic lichens are examples.

Vascular Plants

Western and northwestern Alaska has long been recognized as having the richest array of vascular plants of any region in the circumpolar north (Hulten, 1937, 1968). This is due to a number of factors, the most important of which are as follows. First, the area was never totally glaciated during the later Pleistocene. This means that populations of many species of plants were presumably able to survive *in situ* throughout the period that most of the rest of northern North America was repeatedly glaciated (e.g., Hopkins et al. 1982). It also means that soil formation and various geological process that result in stable substrates have been going on uninterrupted for very long times in comparison to other North American areas, which have often been scoured to bare rock within the past 10,000 to 12,000 years. A second important factor is the location of the area at a place where many of the major mountain ranges of the world converge. The Brooks Range extends thousands of kilometers southward as part of the Rocky Mountains, while similar connected mountain ranges extend deep into central Asia. Thus, the Beringian region has probably long served as a "staging area" for alpine plants that are slowly colonizing the Arctic (Young 1971). Finally, the complex local topography and history of local glacial advance and retreat have created great variety in local habitats in terms of substrate, soils, microclimates and disturbance.

There is currently little agreement or understanding of the responses of vascular plant vegetation to changing conditions, although this field is developing rapidly (e.g., Bradley 1999). Treeline and its advances and possible retreats has been an area of major interest since the mid-20th century, but the processes that influence the spread or retraction of the ranges of conifers are complex enough, and long-term enough, that the documentation and interpretation of changing treeline is still in its early stages. Much recent research deals with changes in nutrient regimes and the stability of various tundra plant communities. This line of investigation is very promising in terms of developing a theoretical framework and set of protocols for monitoring tundra ecosystems and interpreting their response to changing environmental factors (Chapin et al. 2000, Mack et al. 2004).

Many examples of areas of rare or unusual species and communities of vascular plants are known, and undoubtedly many more are to be discovered. An example would be the extensive serpentine barrens in the vicinity of Feniak Lake, in the middle Noatak drainage. This area actually contains a great variety of sub-sites with individual and unique arrays of plants.

Nonvascular Plants

Lichens and bryophytes are a conspicuous and ecologically important element in Alaska's arctic parks. Nonvascular plants are likely to represent 75 to 80% of ARCN's flora (Neitlich and Hasselbach 1998, NPFlora 1989). In many cover types, these plants constitute a co-dominant portion of the biomass (Viereck et al. 1992, Swanson et al. 1985) and account for a significant amount of cover in NPS's satellite imagery-based landcover maps (Markon and Wesser 1997, 1998, Swanson et al. 1985) and vegetation classifications (TNC 1999, Viereck et al. 1992). Because of their fragility, ecological importance as forage, and high sensitivity to impacts from pollution (Pegau 1968, Nash 1988), the inventory and monitoring of lichens and bryophytes is a priority statewide. The ecological roles of Alaska arctic lichens and bryophytes include forage, nesting materials or direct shelter, nitrogen fixation, and primary productivity. Lichens serve as a major food source for many small and large mammals, including muskoxen, Dall's sheep, and ground squirrels (Sharnoff and Rosentreter 1998). An adult caribou typically consumes 5–6 kg/day of lichens during winter (Boertje 1984). Lichen consumers represent a major prey base for several top predators (e.g., wolves, bears, and owls). Lichens represent an exclusive food source for large numbers of arthropods (Gerson 1973) and contribute a small but significant quantity of fixed nitrogen to the region's nutrient-poor, low-productivity ecosystems (Gunther 1989).

Lichens are extremely fragile, slow-growing, and sensitive to air pollution (Richardson 1992). Different lichen species grow between 0.1 mm to about 5 mm per year. Because of slow growth and poor dispersal ability by lichens, attainment of late-successional terrestrial or epiphytic lichen communities can take up to 250 years in boreal and arctic environments (Black and Bliss 1978, Christiansen 1988). Lichens rely entirely on atmospheric inputs of water and nutrients for growth and have evolved to uptake atmospheric inputs readily without barriers of specialized tissue. Because of this, they are extremely susceptible to injury by S and N-based pollutants and acidification (Richardson 1992, McCune 1988). For this same reason, they are also reliable as passive monitors of contaminant accumulation via elemental analysis of tissue (Ford and Vlasova 1996).

Fire Regimes of the Arctic Network

Climate, terrain, and vegetation strongly influence the occurrence and extent of fires within ARCN. The subarctic boreal forests and low arctic tundra biomes are subject to periodic fires. Over the last 50 years, greater than 1.2 million acres have burned within and around ARCN park units, with an annual average of 24,000 acres burned per year, 96% of which are caused by lightening (NPS Fire Records 1956-2005). The frequency and extent of the fires is variable within the park units (Table

2). Fires can exert landscape-scale controls on vegetation structure and composition, permafrost dynamics, nutrient cycling, carbon loss/gain, primary productivity and biodiversity (Racine et al. 2004).

Table 2. Acreage burned in and around the Arctic Network Parklands from 1956-2005. Data includes all fires that have started within the park units, although not all acres are contained within the administrative boundary of the units. Fire information is based on NPS fire records.

	BELA	CAKR	GAAR	KOVA	NOAT	Total ARCN
Total Acres	289,670	4,285	314,215	202,158	430,405	1,240,732
Average acres/yr	5,793	86	6,284	4,043	8,608	24,815
Total # fires	36	5	145	60	135	364
Average # fires/yr	0.7	0.1	2.9	1.2	2.7	
Average fire size (acres)	7,828	857	2,228	3,485	3,188	

The southern third of GAAR lies within the northernmost belt of Interior Alaska, and has the greatest number of fire starts within the Arctic Network. GAAR is on the periphery of interior weather patterns and is occasionally subject to large lightning bursts, associated with low precipitation and high temperatures in June and July. The spruce lichen woodlands, black spruce feather moss and low shrub-tussock tundra types south of the Brooks Range are the most common fuel types burned, with an estimated fire return interval of 100-200 yrs. Fires are infrequent in the northernmost two thirds of GAAR due to the lack of fuels associated with the barren or sparse alpine tundra on the Brooks Ranges and the increased precipitation from the Arctic coastal influence of the North Slope.

The lowlands of the Noatak Valley are subject to periodic large fires and frequent small fires from late May until early August. Fires commonly occur in shrub-tussock tundra, sedge/graminoid lowlands, and shrub thickets of dwarf birch/ericaceous, alder (*Alnus crispa*) or willow (*Salix* spp). More than 95% of Noatak's fires are caused by lightning. Thunderstorm development in the valley can result from synoptic wide-spread storms or localized air-mass storms controlled by local topography. Warm dry air masses within the Noatak Valley can encounter coastal low pressure systems from the west, leading to significant thunder cell development and lightning. When ignitions are accompanied by dry windy conditions, fires in the shrub-tussock tundra and low shrub birch/ericaceous can spread rapidly and burn thousands of acres in a few days.

KOVA is in the transition zone between the interior Alaska forests and northern and western tundra. Fires are most frequent in dryer areas south of the Baird Mountains within open and woodland spruce forests. The greatest number of starts occurs during June. As is typical of boreal forest fires, the fires tend to have longer duration than tundra fires.

The number of fires in CAKN and BELA are much lower due to the wet maritime conditions and lack of ignition sources. Only five fires have been detected in CAKR over the past 50 yrs. No fires have been recorded in the low wetlands of BELA. Inland from the coast, vegetation communities are subject to occasional fires. These vegetation communities are susceptible to fire, but low frequency of lightning (Dissing and Verbyla, 2003) or higher precipitation reduces the number of ignitions within BELA. The majority of acres burned within the preserve occurred during 1977, in which several large fires burned within and around the Preserve. Over the past half century, fire suppression activity on the Seward Peninsula has possibly reduced the number of acres burned in the eastern half of BELA.

Birds of the Arctic Network

Most birds found in the ARCN are summer nesters or migrants, with only about a dozen species overwintering within the network. There is evidence supporting the presence of 177 bird species in the Arctic Network, with individual parks containing between 114 and 132 species (Appendix 8) and as many as 12 to 26 species that have yet to be documented in one or more of the parks (NPSpecies 2004). A certified species list with citations will be available in the fall of 2005, following the completion of final reports of the bird inventory efforts and the quality assurance/quality control process for the NPSpecies database.

Prior to current efforts, the ARCN was largely unsurveyed, leaving a gap in our knowledge of the breeding distribution and habitat requirements of many migrant and resident bird species. Fieldwork for a three-year montane-nesting bird inventory of the network was completed in 2003, with data analysis and final report compilation occurring in 2005. In addition, I&M and the Park Flight Program recently provided support for bird inventories within GAAR for a three-year landbird inventory scheduled for completion in 2005.

The northwest Alaska region provides important bird habitat because it is a major breeding area for migratory birds from as far away as Antarctica. This region encompasses a zone of interchange between the flyways of Asia and North America, and it includes important transitional habitat areas between boreal forest, coastal lands, and tundra.

More than 25 species of waterfowl inhabit the network's wetland areas. All four loon species are found in the Noatak drainage. The lagoons between Cape Krusenstern and Sheshalik are heavily used by migrating waterbirds. This area is also an important subsistence hunting area for waterfowl and as an egg gathering area. It is an important fall staging area for thousands of geese, ducks, shorebirds, and gulls. Prime waterfowl nesting areas also occur in the extensive wet lowlands in the Kobuk Valley. In BELA and CAKR, the marine/estuarine habitat, together with extensive freshwater ponds and lakes, provides resting, nesting, feeding, and molting grounds for large populations of migrating geese, ducks, and shorebirds. The salty grasslands and marshes at the mouths of the Nugnugaluktuk, Pish, and Goodhope rivers and Cape Espenberg are especially important for waterfowl adapted to estuarine conditions.

Raptors find important habitat within the Noatak drainage. Thirteen species of raptors are known in the preserve, and GAAR provides montane nesting habitat for numerous species with breeding ranges limited to Alaska, such as the surfbird and Smith's longspur (Tibbitts et al. 2003).

Of special interest among the remaining birdlife are several Asian species that have extended their ranges into North America along the Bering Land Bridge corridor. These include the wheatear, yellow wagtail, white wagtail, bluethroat, and arctic warbler (Young 1974).

Mammals of the Arctic Network

Approximately 42 species of terrestrial mammals are believed to occur within the boundaries of the Arctic Network park units (Appendix 9), ranging in size from the tiny shrew (*Sorex yukonicus*) to brown bears (*Ursus arctos*) and moose (*Alces alces*). A certified species list with citations will be a vailable in fall 2005, following the completion of final reports of the mammal inventory efforts and the quality assurance/quality control process for the NPSpecies database.

Many northern mammal populations, such as lynx (*Lynx canadensis*), snowshoe hare (*Lepus americanus*), caribou (*Rangifer tarandus*), and lemmings (*Dicrostonyx* spp. and *Lemmus* spp.), are characterized by local, seasonal, or cyclic abundance. Distribution and abundance data are almost nonexistent except for animals hunted for subsistence.

Distributions of northern mammals are changing within historic times, such as the expansion of moose into the western Brooks Range within the last 70 years (Coady 1980) and the extirpation of muskoxen in the mid 19th century and their subsequent reintroduction during the 1970s (Lent 1999). Other species that have recently expanded their ranges north and west into one or more of the arctic park units include beaver and coyotes. Other large changes in populations include the 50 to 70% decline in the GAAR sheep population in the late 1980s, the 70% decline in moose on the drainages on the north side of the Brooks Range in the early 1990s, and the six-fold increase in the Western Arctic caribou herd during the last 25 years (75,000 animals in 1976 to 450,000 in 1999).

Ecological and distribution information about northern mammals is scant compared to that of parks in the contiguous U.S., where small changes in species' ranges are being tracked at a fine scale as species move north and up in altitude, in a possible response to global climate change (Burns et al. 2003). Recent I&M field inventories have demonstrated the paucity of knowledge of even the presence of the few species in the Arctic by providing vouchers for 12 mammal species not previously documented in one or more of the ARCN parks. By park unit, the number of new mammal species documented during inventory fieldwork from 2001 to 2003 were five in GAAR, two in NOAT, eight in KOVA, four in BELA, and six in CAKR. Additional literature searches have located more obscure documentation of an additional 10 species that were not previously thought present in one or more of the ARCN parks. Overall, recent efforts have increased the number of mammal species known to be present in ARCN parks by 19.

Some of the more notable species documented for the first time in one or more of the parks include the tiny shrew (*Sorex yukonicus*) which was newly discovered in GAAR, KOVA, BELA, and CAKR; the pygmy shrew (*S. hoyi*) newly documented in KOVA and CAKR, resulting in a known range extension of approximately 250 kilometers; the barren ground shrew (*S. ugyunak*) discovered in GAAR, BELA, CAKR, and NOAT (previously only documented on the North Slope, these new vouchers resulted in a known range extension of 300 kilometers south); the taiga vole (*Microtus xanthognathus*) in KOVA and NOAT (new vouchers resulting in a 150-kilometer known range extension to the northwest); and the porcupine (*Erethizon dorsatum*) in GAAR, of which few vouchers exist anywhere in the Brooks Range.

Among documented species, large data gaps and questions remain. For example, very few vouchers exist for marmots in Alaska, especially in the Arctic, where it is thought there may be two separate species: the Alaskan marmot and hoary marmot (*Marmota broweri and M. caligata* respectively). Physical differences between these two species are so slight and understudied that no reliable published keys exist for identifying them. It is thought that the two species differ greatly in origin, with the Alaskan marmot being more closely related to Asian marmot species than to any North American marmot species (Olsen pers. comm.). A third species of marmot (*M. monax*), the woodchuck, has expanded its range from the Lower 48 as far north as Fairbanks during previous decades. Additional arctic and subarctic species that are thought to occur in the park but for which no documentation exists include pika (*Ochotona collaris*), bats (*Myotis* spp.), and the tundra hare (*Lepus othus*). Species thought to be expanding their ranges to interior Alaska from Canada include mountain lions (*Felis concolor*) and mule deer (*Odocoileus hemionus*). Range information and monitoring is thought to be especially important for Alaskan species in light of the more dramatic climate changes predicted for the region.

In addition to the terrestrial mammals, it is estimated that more than 13 species of marine mammals use the waters of the Chukchi Sea and Kotzebue Sound adjacent to Cape Krusenstern National Monument and Bering Land Bridge National Preserve. Both BELA and CAKR have mandates for the protection of marine mammal habitat (jurisdiction ends at the high-tide line). Polar bears and seals make dens or have haul-outs on the mainland, and many are frequently sighted in estuarine environments or small bays.

Records of Past Ecosystems and Events

ARCN contains exceptional opportunities for developing a picture of the events and processes that have resulted in the current array of ecosystems, both within the parks and preserves and in the circumpolar Arctic and boreal regions in general (Hopkins et al. 1982, Elias and Brigham-Grette 2000). The evidence ranges from large physical features such as moraines and beach ridges to long-term records of past environmental and climatic trends, such as sediment columns and animal fossils to information derived from archaeological studies.

The importance of studies of this kind for our purposes is that they can establish a known trajectory for the direction and magnitude of ecosystem change and the processes that influence them over long periods of time. When information about the nature of modern ecosystems and the processes occurring within them can be evaluated in relation to long-term environmental changes—or stability— this can greatly increase our ability to discern their significance.

The main reason for this unusual richness of potential paleoenvironmental data is that much of the area was never glaciated during the Pleistocene and thus formed a part of unglaciated Beringia, as the eastern extension of the ancient Eurasian Arctic is often called. Other parts of ARCN were subject to only local glaciation, especially during the latter part of the Pleistocene. Also, some exceptional circumstances, such as the survival of ancient lake sediments at Immuruk Lake and the burial of ancient land surfaces under tephra, such as occurred on the northern Seward Peninsula, have created important opportunities for research.

The ARCN has been inhabited by humans for at least 12,000 to 13,000 years, and perhaps twice as long or even longer. There is abundant evidence for human activities for the past 4,000 to 5,000 years, and a major product of the study of these ancient cultures has been the accumulation of evidence for the nature of the environment in which these people lived. Archaeological studies are not only important in helping to document the role of prehistoric people in the local environment. They also often provide a rich source of data on aspects of the environment that are little affected by the presence of humans. For example, the spread of moose into northwestern Alaska in historic and late precontact times is largely known through the presence or absence of evidence for moose in well-documented archaeological sites throughout the area.

Summary of Unique Resources in ARCN

Unique Geomorphic and Ecological Features of ARCN

The Arctic Network contains many unique geomorphic and ecological features that are found in very few of the nations national parks. Permafrost, glaciers, granitic outcroppings, tors, pingos, taliks, springs, and glacial-fed streams, coastal lagoons, large meandering rivers, maar lakes, lagoons, tundra lakes, and ponds are all parts of the northern Alaska landscape. A sampling of interesting features in ARCN parks includes the Lost Jim lava cone and other lava flows near Imuruk Lake, Serpentine Hot Springs, the coastal lagoons of BELA and CAKR, the sand dunes and Onion Portage in KOVA, and the Noatak River Watershed in GAAR and NOAT.

National Natural Landmarks

The National Natural Landmarks Program recognizes and encourages the conservation of outstanding examples of our country's natural history. It is the only natural areas program of national scope that identifies and recognizes the best examples of biological and geological features in both public and private ownership. National Natural Landmarks are designated by the secretary of the interior. To date, fewer than 600 sites have been designated.

There are two official National Natural Landmarks in ARCN: Walker Lake and Arrigetch Peaks, both located in Gates of the Arctic National Park and Preserve.

- Walker Lake is a mountain lake at the northern limit of forest growth. This lake is on the southern slope of the Brooks Range and supports a full range of ecological communities. Walker Lake was designated a National Natural Landmark in 1968.
- Arrigetch Peaks are located 70 miles west of Bettles in the Brooks Range and were designated a National Natural Landmark in 1968. Carved by glacial ice and running water, they illustrate several phases of alpine glacier activities. The peaks reveal abrupt transitions from metamorphic to granitic rock and contain both boreal forest and tundra ecosystems.

International Biosphere Reserve: The Noatak Watershed

In 1976, The United Nations Educational, Scientific, and Cultural Organization (UNESCO) Man and the Biosphere (MAB) Program designated the Noatak River and its surrounding watershed (more than 3,035,200 acres) as an international biosphere reserve. Biosphere reserves are chosen on the strength of their ability to reconcile the conservation of biological diversity and the sustainable use of biological resources. Biosphere reserves are nominated by member states after a process of consultation and coordination with government agencies, local communities, nongovernmental organizations, and private interests with a stake in the areas concerned. The advantages enjoyed by sites designated as biosphere reserves include official United Nations recognition of local and national efforts to promote conservation and sustainable development; a "label of excellence" that is helpful in securing additional funding; and membership in the World Network of Biosphere Reserves which facilitates the exchange of ideas and scientific research results. The Noatak Biosphere Reserve was established to maintain the environmental integrity of the Noatak River and adjacent uplands, to protect wildlife habitats and populations, and to protect archaeological resources for scientific research.

Outstanding Natural Resource Waters in ARCN

Alaska has a general antidegradation policy for water bodies, but does not have procedures for designating Tier III waters or Outstanding Natural Resource Waters (ONWRs). There are seven Wild and Scenic Rivers in Alaska, which likely will be designated as ONRWs once the antidegradation policy implementation plan is approved.

Alaska's antidegradation policy is identical to federal law and can be found in 18 AAC 70.015. The policy states: (1) existing water uses and the level of water quality necessary to protect existing uses must be maintained and protected; (2) if the quality of a water exceeds levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality must be maintained and protected; (3) if a high-quality water constitutes an outstanding national resource, such as a water of a national or state park or wildlife refuge or a water of exceptional recreational or ecological significance, the quality of that water must be maintained and protected; and (4) if potential water quality impairment associated with a thermal discharge is involved, the antidegradation policy described in this section is subject to 33 USC 1326 (commonly known as Section 316 of the Clean Water Act).

According to the state, many water bodies have natural water quality that is better than the criteria set by the Water Quality Standards. In 1996, Alaska adopted the above antidegradation policy. However, the EPA also requires the state to develop an Antidegradation Policy Implementation Plan. The plan will specify the procedures and criteria used to determine when waters are degraded by point or nonpoint sources of pollution and what social and economic benefit to the state would be necessary to justify any degradation. The plan will also have procedures for nomination and designation of outstanding natural resource waters (ONRW). Alaska is in the process of developing this plan.

Wild and Scenic Rivers

Under the authority of the Wild and Scenic Rivers Act of 1968, congress created the National Wild and Scenic Rivers System. In October of 1968, the Wild and Scenic Rivers Act pronounced that "certain selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations." Seven rivers in ARCN parks were designated as "wild" on December 2, 1980, under this act, including the Alatna, John, Kobuk, Noatak, North Fork Koyukuk, Salmon, and Tinayguk rivers. Wild river areas are defined as those rivers or sections of rivers that are free of impoundments and generally inaccessible except by trail, with watersheds or shorelines essentially primitive and waters unpolluted. The Alatna River (83 miles, 133 km) and North Fork Koyukuk (102 miles, 163 km), which are wholly within Gates of the Arctic National Park, are designated as "Wild" for their entirety. The 52-mile (83 km) segment of the John River within Gates of the Arctic National Park is designated as "wild." From its headwaters in the Endicott Mountains and Walker Lake in Gates of the Arctic National Park and Preserve, the Kobuk River is also designated as "wild" (110 miles, 160 km). The Noatak River from its source in Gates of the Arctic National Park to the Kelly River in the Noatak National Preserve (330 total miles, 528 km) is designated as "wild." The Salmon River within the Kobuk Valley National Park (70 miles, 112 km), and the Tinayguk River in Gates of the Arctic National Park and Preserve (44 miles, 70 km) are also designated as "wild."

Potential Resource Concerns for ARCN

The National Program has created a NPS Ecological Monitoring Framework that is a systems-based, hierarchical, organizational tool for promoting communication, collaboration, and coordination among parks, networks, programs, and agencies involved in ecological monitoring.

Networks embarking on selecting vital signs (Phase 2) and protocol development (Phase 3) of those vital signs are using this framework for assigning vital signs to the Level 3 category. Since ARCN has not yet selected its vital signs, we are using this framework to show potential resource concerns for each of the parks (Table 3). It is our hope that by organizing our thoughts into the national framework early in designing our monitoring program, we will facilitate collaboration among networks.

Issues of concern for resource management in the ARCN parklands are myriad and perhaps more unique than those faced by managers in the Lower 48 states. The arctic is a harsh environment with wide variety in physical extremes, including day lengths and temperatures that vary dramatically by season. Conditions of low precipitation, perpetually frozen soils, low biodiversity, and relatively simple, though idiosyncratic, habitat systems abound among varied landscapes, including tundra estuaries, beaches, lagoons, dunes, thick boreal forests, shrublands, and extensive wetlands.

While most national parklands do not allow consumptive use of their resources, the Arctic Network is different. The enabling legislation for these parks accommodates the continuing tradition of subsistence use of resources by neighboring communities. People have been harvesting game and fish from areas in and around the parks for thousands of years. With the acquisition of the parks came the responsibility to maintain these subsistence resources in good condition. Accomplishing this task will require monitoring the population ecology of subsistence animals in order to provide accurate baseline information to managers.

Pollution is also a concern in the arctic. The seemingly pristine appearance of the region belies the fact that it is unceasingly bombarded by pollutants from both local and global industry. Arctic haze, contamination by persistent organic pollutants (POPs) and heavy metals, and condensation and bioaccumulation of pollutants are also issues of management concern for arctic parks.

Climatic stressors may be the foremost issues that park management will deal with. Models indicate that subtle climate changes will have the most dramatic effect in arctic regions. These changes will be observable in many attributes of the arctic system, including thermokarst dynamics, thaw lakes, active layer depth, snowpack persistence, variations in timing of wildlife migrations, plant phenology, greenup, treeline dynamics, albedo, and sea ice extent and duration. Of all known arctic ecosystem drivers, climate has the greatest potential to cause pronounced, cascading effects on arctic processes and subsystems.

Permafrost dynamics should figure prominently in any effort to monitor arctic ecosystems. Perennially frozen soils dictate land drainage complexity, vegetation assemblages, and mechanics of nutrient cycling and sequestration. Thermokarst, peat, water discharge, and soil hydrology are all affected by underlying soil characteristics and each of these in turn could have a profound influence on landscape-level plant community structure and habitat patterns.

Despite the physiognomic differences in each of the arctic parks, water plays a consistent and powerful role in each of them. From sea ice, coastal erosion, brackish lagoons and estuaries along the coast to freshwater travel corridors, karst ponds, wetlands, permafrost and glaciers in the interior, water ultimately sculpts the land and dictates the distribution and abundance of species. Water quality must remain high to

Table 3: Potential resource concerns in the context of the National Ecological Monitoring Framework"
(X indicates a potential resource concern for the park, preserve or monument, – indicates low likelihood of a resource concern for the park, preserve or monument). Specific concerns of high pertinence to the Arctic Network are listed in the last column.

National Ecological Monitoring Framework			**Potential Resource Concerns**					**Major Specific Concerns**
Level 1 Category	**Level 2 Category**	**Level 3 Category**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**	**Any or All Parks**
Air and Climate	Air Quality	Ozone	–	–	–	–	–	–
		Wet and Dry Deposition	X	X	X	X	X	POPs, Metals, Nitrates, Sulfates
		Visibility and Particulate Matter	X	X	X	X	X	Arctic Haze
		Air Contaminants	X	X	X	X	X	Arctic Haze
	Weather and Climate	Weather and Climate (Climate Change)	X	X	X	X	X	Climate Change
Geology and Soils	Geomorphology	Windblown Features and Processes	X	X	X	X	X	Kobuk Dunes Ecosystem
		Glacial Features and Processes	–	–	X	–	X	Glacier retreat
		Hillslope Features and Processes	X	X	X	X	X	Erosion, Solifluction
		Coastal/ Oceanographic Features and Processes	X	X	–	–	–	Sea Ice
		Marine Features and Processes	X	X	–	–	–	Prevailing Currents, Marine–derived Food Sources
		Stream/River Channel Characteristics	X	X	X	X	X	
		Lake Features and Processes	X	X	X	X	X	Thermokarst, Drainage, Eutrophication, Water Quality
	Subsurface Geologic Processes	Geothermal Features and Processes	X	–	X	–	–	Unique Microhabitats, Human Use/ Development
		Cave/Karst Features and Processes	–	–	–	–	–	
		Volcanic Features and Processes	–	–	–	–	–	
		Seismic Activity	–	–	–	–	–	
	Soil Quality	Soil Function and Dynamics	X	X	X	X	X	Thermokarst, Nutrient Cycling/ Sequestration
	Paleontology	Paleontology	X	X	X	X	X	Paleoresource Protection

(continued on next page)

National Ecological Monitoring Framework			Potential Resource Concerns					Major Specific Concerns
Level 1 Category	**Level 2 Category**	**Level 3 Category**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**	**Any or All Parks**
Water	Hydrology	Groundwater Dynamics	X	X	X	X	X	Permafrost, Groundwater Dynamics
		Surface Water Dynamics	X	X	X	X	X	Permafrost, Surface Water Dynamics
		Marine Hydrology	X	X				
	Water Quality	Water Chemistry	X	X	X	X	X	Eutrophication, Water Quality
		Nutrient Dynamics	X	X	X	X	X	Nutrient Dynamics
		Toxics	–	X	–	–	X	Pollution, Human Waste/Chemical Spills
		Microorganisms	X	X	X	X	X	
		Aquatic Macroinvertebrates and Algae	X	X	X	X	X	
Biological Integrity	Invasive Species	Invasive/Exotic Plants	–	X	X	–	–	
		Invasive/Exotic Animals	–	–	–	–	–	
	Infestations and Disease	Insect Pests	X	X	X	X	X	Spruce Beetle, Defoliators
		Plant Diseases	X	X	X	X	X	Vectors, Transmission Mechanics, Outbreaks
		Animal Diseases	X	X	X	X	X	Avian Flu, Pneumonial, Lice, Pasteurellosis, Johanssen's Disease, Brucellosis, etc.
	Focal Species or Communities	Marine Communities	–	–	–	–	–	
		Intertidal Communities	X	X	–	–	–	
		Estuarine Communities	X	X	–	–	–	
		Wetland Communities	X	X	X	X	X	Lagoon Ecology
		Riparian Communities	X	X	X	X	X	
		Freshwater Communities	X	X	X	X	X	
		Sparsely Vegetated Communities	X	X	X	X	X	Rare, unique microhabitats, distribution/area
		Cave Communities	–	–	–	–	–	
		Desert Communities	–	–	–	–	–	
		Grassland/Herbaceous Communities	X	X	X	X	X	

(continued …)

National Ecological Monitoring Framework			Potential Resource Concerns					Major Specific Concerns
Level 1 Category	**Level 2 Category**	**Level 3 Category**	**BELA**	**CAKR**	**GAAR**	**KOVA**	**NOAT**	**Any or All Parks**
		Shrubland Communities	X	X	X	X	X	
		Forest/Woodland Communities	X	–	X	X	X	
		Marine Invertebrates	–	–	–	–	–	
		Freshwater Invertebrates	X	X	X	X	X	
		Terrestrial Invertebrates	X	X	X	X	X	
		Fishes	X	X	X	X	X	Resident Fish, Subsistence
		Amphibians and Reptiles	–	–	–	–	–	
		Birds	X	X	X	X	X	
		Mammals	X	X	X	X	X	
		Vegetation Complex (use sparingly)	X	X	X	X	X	
		Terrestrial Complex (use sparingly)	X	X	X	X	X	
	At-risk Biota	T&E Species and Communities	X	X	X	X	X	
Human Use	Point Source Human Effects	Point Source Human Effects	–	X	X	–	X	Mining/Industrial Pollution, Human Waste, ATV, Trash
	Nonpoint Source Human Effects	Non–point Source Human Effects	X	X	X	X	X	Arctic Haze, Industrial Pollution, Bioaccumulation
	Consumptive Use	Consumptive Use	X	X	X	X	X	
	Visitor and Recreation Use	Visitor Use	X	X	X	X	X	
	Cultural Landscapes	Cultural Landscapes	X	X	X	X	X	
Landscapes (Ecosystem Pattern and Processes)	Fire and Fuel Dynamics	Fire and Fuel Dynamics	X	X	X	X	X	Habitat, Thermokarst
	Landscape Dynamics	Land Cover and Use	X	X	X	X	X	Development, NPRA, Coal, Oil, Mining, 2477 Roads, Treeline, Plant Community Distribution
	Extreme Disturbance Events	Extreme Disturbance Events	X	X	X	X	X	Fire, Coastal Erosion
	Soundscape	Soundscape	–	–	X	–	–	
	Viewscape	Viewscape/Dark Night Sky	–	–	–	–	–	
	Nutrient Dynamics	Nutrient Dynamics	X	X	X	X	X	Carbon Sequestration/ Release
	Energy Flow	Primary Production	X	X	X	X	X	

maintain subsistence plants and animals in good condition, particularly fish species. Both legislators and park visitors demand that National Wild and Scenic Rivers have clean water, and our choices in vital signs must reflect water quality issues.

The effect of water on the environment is not limited to its chemical makeup. Water is also a powerful geophysical force, physically changing the landscape in dramatic ways. Shoreline erosion is becoming a severe issue to communities in the Bering Strait and Chukchi Sea and may adversely affect the stability of unique coastal habitats including lagoons, estuaries, and near-shore riverbanks. Thermokarst action and natural lake drainage continually changes the face of certain landscapes. The net result of these processes is an ephemeral and dynamic system of water bodies that easily appear and disappear by draining, drying, slumping and infilling. From a monitoring perspective it may be important to quantify the variability of these processes and to better understand their consequences to park resource values, particularly since they are demonstrably sensitive to climate trends.

Baseline inventories of water bodies and animal, microbial, and plant assemblages will be of particular interest to our monitoring program. Migration and breeding times and locations of animals, plant green-up, flowering and senescence are sensitive to environmental changes. In addition, exploitation of preexisting but unused rights-of-way for road construction may provide new mechanisms for dispersal of invasive and noxious species as well as increased human traffic and the accompanying mélange of detrimental effects. Finally, the sheer size of the parks provides for a large variety of very specialized microhabitats and associated rare species. These habitats and the viability and characteristics of their resident organisms should be inventoried and monitored to establish baseline information.

Subsistence and consumptive resource uses are allowed in many of the arctic parks and, consequently, add a layer of complexity to park management. Habitat quality and game and fish populations are important to local communities and must be managed, protected, and preserved. We expect that access to the parks will be improved over time and exploitation of these resources will need to be monitored. All-terrain vehicle use is increasing, particularly near remote communities, and these vehicles leave an indelibly detrimental mark on the landscape, in addition to disturbing wildlife and increasing pollution and trash dispersal.

Little specific information is available on the long-term impacts of human activities on the arctic ecosystem. Potentially quantifiable effects include trash buildup, pollution of many sorts, human waste, leaking fuel drums, petroleum spills, mining and industrial enterprises, hazardous dust, and the various impacts of oil and gas exploration. These issues will have to be prioritized and included in our monitoring plan.

One more focus area for the monitoring program is in landscape-level processes. The ecology of the arctic parks is dynamic and the functionality of the system is greatly affected by broad cycles and trends, both anthropogenically induced and natural. Fire is a common disturbance agent, influencing both forested river valleys and open tundra. Fire can significantly alter habitat, thaw permafrost, modify hydrological and successional patterns, and plays a significant role in nutrient cycling.

Another major component driving the state of coastal park ecosystems is the timing, distribution, and duration of sea ice. Sea ice can have a large impact on predator-prey relationships of both sea and terrestrial mammals as well as on subsistence activities. Broad-scale climatic factors influencing the spatial arrangement of animals and plants include basic ranges of temperature and precipitation but also feedback loops driven by prevailing weather patterns cloudiness and albedo.

A review of this very basic introduction to possible vital signs elucidates the challenges we face as we proceed into Phase 2 of our program. All the factors mentioned above may act in unique ways to augment potential anthropogenic threats to arctic ecosystems. The vital signs we select must be pertinent to management, sensitive to anthropogenic change, have a known or easily determined level of variance, and be inexpensive to measure and analyze. In light of these requirements and the vast array of possibilities, vital sign selection may well be the toughest step faced by the program.

Potential Monitoring Objectives for ARCN

The monitoring program of the Arctic Network will be designed around the five service-wide goals. In order to detect change at the ecosystem, community, or population scale, these five goals must be refined to more specific monitoring questions. What follows are potential monitoring questions that were developed during the first three scoping workshops: the freshwater, coastal, and terrestrial workshops. These questions were developed then ranked by the experts in terms of relevance to the monitoring program. The rankings are omitted here. These questions have not in any way been chosen as final monitoring questions or vital signs, but rather show the range of topics and issues identified by an expert panel as pertinent to an arctic monitoring program. The final monitoring questions and vital signs will be selected from or modified from the list below.

Draft Monitoring Objectives for Freshwater Ecosystems

Objective 1: Collect baseline data on the physical, chemical, and biological parameters of streams, lakes, wetlands, and surrounding watersheds within the ARCN.

Objective 2: Determine long-term trends in the physical, chemical, and biological characteristics of streams, lakes, wetlands, and surrounding watersheds within ARCN.

Objective 3: Understand how landscape components interact at various spatial and temporal scales to affect freshwater ecosystems.

Potential Monitoring Questions for Freshwater Ecosystems of the Arctic Network

I. Streams Working Group

Question 1: How do we monitor change in flow and temperature regimes to document annual hydrologic patterns in streams?
Attribute (Component/Process): *stream temperature, stream flow/discharge*

Question 2: What is the location and distribution of spring ecosystems (groundwater upwelling areas) in ARCN? What is the amount of ice deposition due to these upwelling areas? What is the importance of springs to fish as spawning and overwintering habitat?
Attribute (Component/Process): *document location of springs and groundwater upwelling areas, flow dynamics of springs, distribution of fish in relation to spring areas*

Question 3: Are there significant shifts in biodiversity and/or ecosystem processes in streams due to global warming?
Attribute (Component/Process): *stream invertebrates, fish, changes in stream food webs*

Question 4: What changes in water chemistry are occurring? What is its influence on primary productivity?
Attribute (Component/Process): *pH, turbidity, nitrogen, phosphorus, chlorophyll, algal and plant biomass*

Question 5: How are spawning sheefish (*Stendous leucichthys nelma* [Pallas]), also known locally as *inconnu*, populations changing due to past and current harvest practices?
Attribute (Component/Process): *sheefish population*

Question 6: Are sediment dynamics changing?
Attribute (Component/Process): *stream substrate composition, channel morphology, and streambed characteristics*

Question 7: How will the distribution of marine-derived nutrients change over time? Will there be a decrease in marine-derived nutrients moving upstream? How will in-stream food webs upstream be effected? Riparian species? Upland Species?
Attribute (Component/Process): *marine-derived nutrients (N, C, Si)*

Question 8: What is the water quality currently downstream from villages? From the Red Dog Mine? How is water quality in this use area

changing over time? Are any wild and scenic rivers being impacted downstream?
Attribute (Component/Process): *water quality in and around areas influenced by industrial and human development, natural vs. anthropogenic inputs of minerals to water bodies*

Question 9: What are the long-term changes in riparian communities along river corridors and what is the effect of those changes on stream communities and ecosystem function?
Attribute (Component/Process): *changes in vertebrates (mammals and birds), invertebrates, and vegetation in the riparian zone*

Question 10: How are aquatic invertebrate abundance, biomass, and diversity responding to human-induced change?
Attribute (Component/Process): *stream invertebrates (invertebrates as indicators of stream condition, change in invertebrates along a longitudinal gradient, invertebrate diversity, abundance, biomass, and functional groups); macroinvertebrate community indices, e.g., RIVPACS (River Invertebrate Prediction and Classification System), EPA Rapid Bioassessment Protocols, IBI.*

II. Lakes Working Group

Question 1: How will expected climate change affect the ecosystem of lakes? How do hydrogeomorphic changes affect hydrology?
Attribute (Component/Process): *assessment of impact of arctic climate change, including (1) slumping of lake shorelines: additions of organic matter, changes in nutrient concentrations; (2) lake drying; (3) extension of growing season; (4) warming of lakes: changes in organism life histories (growth rates, reproductive success) or diversity, potential for exotic species introductions and establishment, changes in timing of ice off, increase in parasitism, shifts in range extensions, changes in nutrient cycles associated with warming, changes in range extensions due to changes in habitat availability because of modifications in timing and extent of ice thickness, changes in thermal stratification in lakes, changes in spawning periodicity; (5) treeline changes: changes in riparian corridor, changes in light environment due to coarse organic matter from shifts in riparian tree species, changes in fire regime and the cascading effects on nutrient regime, changes in sediment loads; (6) potential changes in precipitation, water residence time, lake level and associated changes; and (7) long-term survival of lakes: physical and chemical changes, disturbance regime, especially disturbance to sea level rise, storm surges, sedimentation, salinization, lake stratification changes, loss of glaciers, changes to turbidity, changes in total dissolved solids*

Question 2: How do changes in inputs of nutrients affect the biota and productivity of lake ecosystems? How do changes in the nutrient regime in lakes affect the structure and function of resident biota? (Note: we understand that these are process-related questions that need to be rephrased for monitoring.)

Attribute (Component/Process): eutrophication (enrichment and change in biota and processes caused by increased loading of nutrients)

Question 3: What are the impacts of consumptive use on lotic and lentic ecosystems?
Attribute (Component/Process): *consumptive harvest of fish and waterfowl*

Question 4: Are contaminants present and in what ecosystem compartments (biotic or abiotic)? What are the sources and pathways of contaminants?
Attribute (Component/Process): *Contaminants, specifically (1) metals: mercury, lead, cadmium, nickel, etc.; (2) organic compounds: persistent organic pollutants (POPs) and semi-volatile organic compounds (SOCs); bioaccumulation of all contaminants; (3) acidic precursors: nitrogen/sulphur; (4) natural versus anthropogenic sources*

Question 5: How is diversity and species composition in ARCN lakes and streams changing in response to human-induced environmental change?
Attribute (Component/Process): *biodiversity of organisms in lakes and streams (entire community, all groups)*

Question 6: How are the physical and chemical constituents of lake ecosystems changing?
Attribute (Component/Process): *chemical and physical processes in lakes*

Question 7: How do local plant and animal populations affect the nutrient regimes in lotic systems? How are terrestrial inputs to aquatic ecosystems changing? How are aquatic inputs to terrestrial ecosystems changing?
Attribute (Component/Process): *terrestrial inputs to aquatic ecosystems, aquatic inputs to terrestrial systems*

Question 8: What changes can we detect by studying lake sediments?
Attribute (Component/Process): *paleo-trajectory*

III. Watershed Dynamics Working Group

Question 1: What is the best approach to inventorying and classifying streams, lakes, and wetlands in these remote parks?
Attribute (Component/Process): *stream, river, lake and wetland inventories and classifications; surface age, underlying geology, surficial geology, soils and physiography; invertebrates; fish; life history of fishes (e.g., migration, overwintering, spawning and rearing)*

Question 2: To what degree are snowfields and glaciers changing?
Attribute (Component/Process): *extent of snowfields and glaciers*

Question 3: Are valley and channel morphology changing (including solifluction)?
Attribute (Component/Process): *extent of river bank erosion*

Question 4: Is the duration and thickness of ice changing?
Attribute (Component/Process): *changes in ice thickness over time in both lakes and rivers*

Question 5: Are the volume and distribution patterns of standing water changing?
Attribute (Component/Process): *pond and lake drying, change in volume (depth), size and shape of lakes and ponds*

Question 6: Is flood frequency and extent changing?
Attribute (Component/Process): *flooding*

Question 7: Are changes in land cover and vegetation composition occurring? How are changes in land cover and vegetation composition affecting aquatic ecosystems?
Attribute (Component/Process): *Spatial and temporal variability in land cover and various related indices (e.g., Normalized Difference Vegetation Index); detailed changes in the plant species composition (biodiversity and changes in species composition); riparian zone vegetation changes; unique features of the landscape*

Question 8: Has the composition of stream beds changed over time due to changes in physical characteristics of streams?
Attribute (Component/Process): *pebble counts*

Question 9: Could macroinvertebrates be used as indicators of stream and lake condition?
Attribute (Component/Process): *stream invertebrates*

Question 10: How is the counter flux of energy, nutrients, and organisms changing due to the cumulative impacts of global warming?
Attribute (Component/Process): *changes in aquatic invertebrate emergence, change in anadromous fish movement upstream, near-stream*

productivity, flux of aquatic-derived nutrients and energy into upland areas via invertebrate predators, birds, and mammals.

Question 11: How is water quality changing in rivers and lakes of ARCN?
Attribute (Component/Process): *various water quality measurements*

Question 12: Is the extent and distribution of thermokarsts increasing due to the increased warming trend in the arctic? How are changes in permafrost and increased thawing (increases in the size of the active layer) due to the current warming trend and related changes in precipitation (rain and snow) effecting hydrologic networks in ARCN?
Attribute (Component/Process): *greater extent of thawing and slumping into rivers and lakes, measure permafrost characteristics (depth to thaw, extent and thickness of active layer) in areas of thermokarst formation, amount and timing of precipitation (snow and rain)*

Question 13: How is climate in ARCN changing? How are precipitation regimes changing over time? How are aquatic ecosystems being effected?
Attribute (Component/Process): *timing and extent of precipitation, amount of precipitation as snow and rain, timing of break-up and snow melt, soil moisture, fire, depth of thaw, permafrost, cloud cover, soil temperature and albedo, mass balance*

Question 14: What is the location and distribution of spring ecosystems (groundwater upwelling areas) in ARCN? What is the amount of ice deposition due to these upwelling areas?
Attribute (Component/Process): *document location of springs and groundwater upwelling areas, flow dynamics of springs*

Question 15: How are the status and trajectory of landscape-level water resources changing due to climate change and anthropogenic inputs? Are key components of the lake and stream network changing?
Attribute (Component/Process): *connectivity, snow fields, drainage patterns (e.g., presence of water tracks), permafrost, bank erosion or deposition, fluvial geomorphology*

Draft Monitoring Objectives for Coastal Ecosystems

Objective 1: Collect baseline data on the physical, chemical, and biological parameters of near-shore waters, intertidal and subtidal zones, beaches, coastal uplands, lagoons, estuaries, and coastal wetlands within the ARCN.

Objective 2: Determine long-term trends in the physical, chemical, and biological characteristics of near-shore waters, subtidal and intertidal zones, beaches, coastal uplands, lagoons, estuaries, and coastal wetlands within ARCN.

Objective 3: Understand how landscape components interact at various spatial and temporal scales to affect these coastal-influenced ecosystems.

Potential Monitoring Questions for Coastal Ecosystems of the Arctic Network

I. Coastal Wetlands Working Group

Question 1: Are there significant shifts in biodiversity in coastal ecosystems over time?
Attribute (Component/Process): *species composition (species richness, diversity, and distribution)*

Question 2: Are there spatial and temporal changes in permafrost?
Attribute (Component/Process): *snow temperature and snow pack (hardness, density, depth, and length of season), soil temperature, increase or decrease in active layer*

Question 3: What are the cumulative effects of fragmentation and its effect on population migrations?
Attribute (Component/Process): *landscape-scale fragmentation, changes in migratory species patterns*

Question 4: How is water quantity and distribution of water bodies changing?
Attribute (Component/Process): *addition or deletion of ponds (net gain or loss numbers and extent of ponds)*

Question 5: How is climate change affecting coastal wetlands?
Attribute (Component/Process): *changes in temperature and precipitation, wind speed and direction, cloud cover (solar input), snow cover (hardness, density, depth, and length of season), ice cover, and albedo.*

Question 6: Is the frequency and intensity of disturbance regimes changing over time in coastal ecosystems?
Attribute (Component/Process): *increase in storm activity, fire, insect outbreaks, beach erosion, size and extent of water bodies*

Question 7: What flora and fauna are present along rocky coasts (which are less than 1% of the total coastline in CAKR and BELA)?
Attribute (Component/Process): *invertebrates, vegetation*

Question 8: What are the levels of contaminants in coastal food webs and how have they changed over time?
Attribute (Component/Process): *historical lake sediments, stratigraphic profiles of permafrost and sedimentary rock*

Question 9: How is the abundance, diversity, and productivity of species living in coastal habitats changing?
Attribute (Component/Process): *bird abundance, diversity and reproductive capacity; changes in composition and productivity of coastal vegetation; changes in coastal invertebrates; changes in rare and endemic species populations; expansion of native species into the parks; presence and distribution of invasive/exotic species*

Question 10: What are the fish populations in delta ecosystems and coastal lakes?
Attribute (Component/Process): *fish*

Question 11: What are the flow dynamics in delta ecosystems?
Attribute (Component/Process): *discharge, sediments*

Question 12: What is the rate of beach erosion and deposition?
Attribute (Component/Process): *sedimentation and erosion rates, shoreline profile and topography*

Question 13: What rare ecosystems are present in coastal ecosystems of the ARCN parks?
Attribute (Component/Process): *identification of rare communities and ecosystems (e.g., dry forb meadows)*

II. Lagoons/Estuaries Working Group

Question 1: How are nutrients cycled in the "open" and "closed" coastal lagoon systems of CAKR and BELA? Are nutrient levels changing?
Attribute (Component/Process): *nitrogen, phosphorus, sulfur*

Question 2: How is carbon cycled in the "open" and "closed" coastal lagoon systems of CAKR and BELA?
Attribute (Component/Process): *primary productivity and decomposition*

Question 3: What are the annual parameters of ice and snow cover in lagoons and estuaries?
Attribute (Component/Process): *salinity, oxygen saturation, temperature, primary productivity,snow and ice depth and density*

Question 4: What are the human uses of lagoons and estuaries?
Attribute (Component/Process): *human use*

Question 5: What are the sources and levels of contaminates in lagoon systems in the arctic coastal parks?
Attribute (Component/Process): *metals and persistent organic pollutant loads in water, air, and benthic and pelagic lagoon organisms*

Question 6: What is species composition and relative abundance of the biotic communities in lagoons and estuaries in summer?
Attribute (Component/Process): *species composition and relative abundance of species in lagoon food webs*

Question 7: What processes are driving lagoon formation and stability?
Attribute (Component/Process): *physical parameters of lagoons (i.e., location, size, connectivity to the sea)*

III. Shorelines Working Group

Question 1: Are sandy and gravelly shorelines in CAKR and BELA eroding? At what rate?
Attribute (Component/Process): *coastal shorelines (width, extent and thickness), dune formation or loss, changes in shoreline vegetation*

Question 2: What are the hydrodynamic responses of lagoons to beach erosion?
Attribute (Component/Process): *coastal shorelines (width, extent, and thickness) in front of closed lagoons, dune formation or loss in areas adjacent to lagoons, changes in the hydrologic response of lagoons (e.g., more salt water intrusion)*

Question 3: How are off-shore bars, beach shelves and near-shore systems changing?
Attribute (Component/Process): *presence of off-shore bars; sand volume*

Question 4: Is trash on beaches due to spills (fuel drums, shipping losses, furniture, etc.), dumping, or erosion (garbage from local communities) increasing, and what is its effect on species using coastal areas? What is its effect on accretion or erosion of coastal habitats?
Attribute (Component/Process): *trash abundance and distribution and relative hazard of trash*

Question 5: What is the effect of ice cover change and open ocean season on shoreline ecosystems?
Attribute (Component/Process): *timing of sea ice melting and snow pack*
Potential Driver/Stressor of Change: *climate change*

Question 6: What is the nutrient enrichment on beaches due to added detrital matter (sea mammal carcasses, vegetation, sea stars, driftwood, human waste, bird guano)?
Attribute (Component/Process): *nutrient inputs (nitrogen or phosphorus); energy inputs (carbon), density of vertebrate predators or detritivores (birds, mammals) along the shore, amount of debris*

Question 7: Will rocky coasts experience erosion due to changes in the frequency and intensity of the freeze/thaw cycle?
Attribute (Component/Process): *timing of sea ice melting and snow pack*

Question 8: Will tundra coasts experience accelerated erosion due to thermokarst formation and marine influences (such as sea ice)?
Attribute (Component/Process): *areas of tundra and permafrost erosion*

IV. Near-shore Waters Working Group

Question 1: How does the coastal current change over time in the near shore waters adjacent to the ARCN coastal parks?
Attribute (Component/Process): *river discharge patterns, annual and seasonal currents, sediment inputs*

Question 2: How will human uses of the near-shore change over time, both in summer and winter?
Attribute (Component/Process): *all human dimensions of change (e.g., numbers, density)*

Question 3: What are the changing contributions of phytoplankton, epontic algae, and macrophytes to primary productivity?
Attribute (Component/Process): *carbon fixed by phytoplankton blooms, carbon from epontic algae, macrophyte distribution, carbon contribution*

Question 4: What are the long-term changes in the trophic structure and dynamics of the near-shore in ice-bound and open water seasons?
Attribute (Component/Process): *arctic cod, seals*

Question 5: What is the water quality of discharge from Kotzebue Sound and how does it change over time? What is the near-shore water quality near the Red Dog Mine port site and how does it change over time?
Attribute (Component/Process): *water clarity, sediment loads, temperature, nitrogen loads, heavy metals*

Question 6: What is the annual and seasonal variability in timing and extent of shorefast sea ice?
Attribute (Component/Process): *timing of ice out, fast ice extent, ice thickness, ice topography (smoothness, presence of pressure ridges)*

Question 7: What is the variability in annual snowcover on shorefast sea ice?
Attribute (Component/Process): *onset and timing of snow cover, snow depth, timing of snow melt, seasonal variability of snow cover*

Draft Monitoring Objectives for Terrestrial Ecosystems

Objective 1: Collect baseline data on the physical, chemical, and biological parameters of tundra and boreal forests within the Arctic Network of parklands.

Objective 2: Determine long-term trends in the physical, chemical, and biological characteristics of boreal and tundra ecosystems within the Arctic Network of parklands.

Objective 3: Understand interactions between landscape components at various spatial and temporal scales and their affects on terrestrial ecosystems.

Potential Monitoring Questions for Terrestrial Ecosystems of ARCN

I. Biodiversity in Terrestrial Ecosystems

Question 1: How is climate change altering biodiversity and species distribution in the Arctic Network?
Attribute (Component/Process): *alteration of species diversity and community composition in response to climate change indicators*

Question 2: How do shifts in human-caused perturbations (e.g., fire regime, airborne pollutants, consumptive vs. nonconsumptive resource use and herbivory) affect biodiversity and native species composition?
Attribute (Component/Process): *altered species diversity and community composition in response to human-caused perturbations (experimental manipulation of ecosystems)*

Question 3: How will changes in biodiversity alter key ecosystem processes in the Arctic Network?
Attribute (Component/Process): *nitrogen fixation, primary and secondary production, nutrient dynamics*

Question 4: How is ARCN biodiversity affected by landscape-level changes in habitat type and distribution (e.g., proportion of total area as wetlands)?
Attribute (Component/Process): *land cover change*

II. Biogeochemistry of Terrestrial Ecosystems

Question 1: What are the impacts of melting permafrost on nutrient cycling and element transport in the parks?
Attribute (Component/Process): *permafrost (presence, depth), active soil layer (nutrient status, temperature), and thermokarsts (distribution)*

Question 2: What are trajectories of climate change in ARCN parks?
Attribute (Component/Process): *ambient temperature, precipitation, snow cover, solar radiation, cloud cover, storm tracks, wind speed and direction, extreme events, and spatial distribution of weather patterns*

Question 3: Are contaminant levels in terrestrial ecosystems of the Arctic Network changing?
Attribute (Component/Process): *contaminant loads in snow cover, soil organic matter, vegetation, invertebrates, birds, and mammals*

Question 4: Which biogeochemical cycles are most sensitive to changing biodiversity and associated shifts in community structure (e.g., relative abundance of functional groups)? Which type of organism found in the parks is most impacted by altered biogeochemical cycles?
Attribute (Component/Process): *nutrient dynamics (nitrogen, carbon, and phosphorus), species and/or functional groups that are impacted by change in nutrient status*

Question 5: Which interactions between, and traits of, species most impact biogeochemical cycling? How do invasive species and species loss effect biogeochemical cycling in the parks?
Attribute (Component/Process): *changes in species traits (e.g., growth form), ecosystem-level function (e.g., abundance and distribution), and interactions (e.g., plant-soil-herbivore interactions, alteration of C, N, P, and S fluxes)*

Question 6: What is the relative importance of physical and biological processes in regulating biogeochemical cycling in the ARCN?
Attribute (Component/Process): *physical processes (permafrost freezing/thawing, thermokarsting, hydrology, radiation, cloudiness, landscape features) in relation to species composition*

Question 7: How will long-term climate change affect reservoirs of soil carbon and impact large-scale nutrient dynamics within the Arctic Network?
Attribute (Component/Process): *melting permafrost, changing decomposition rates, carbon release, and available nitrogen and phosphorus*

Question 8: In what way does variation in short-term climate regime (e.g., seasonality) influence biogeochemical cycling in ARCN?
Attribute (Component/Process): *seasonal coupling of biological components with climate variability (e.g., seasonal vegetation quality, snow pack persistence, precipitation, timing and distribution of mammal migration, seasonal forage quality, key biogeochemical processes, species composition and abundance, plant community composition)*

Question 9: Can paleorecords of changes in element cycling inform us of current dynamics?
Attribute (Component/Process): *paleorecords from lake cores as indicators of historical species (distribution, composition, and invasion) and ecosystem productivity*

Question 10: In ARCN parks does human land and resource use ameliorate and/or perpetuate current trends and patterns of biogeochemical cycling?
Attribute (Component/Process): *human impacts (e.g., industrial development, subsistence, and recreational use) on key biogeochemical processes (hydrology, species density, aerosols)*

Question 11: What are the consequences of changing the balance of nutrient inputs (C, N, P, Si, Fe, S)? Do increased inputs translate into accelerated cycling within ecosystems and changes in retention and export?
Attribute (Component/Process): *key biogeochemical processes, inputs, element stocks and fluxes, aerosol measurements, nitrogen fixation, nutrient retention, and export of key elements*

Question 12: How do inputs of trace metals, pollutants, and organic matter interact with biogeochemical cycles?
Attribute (Component/Process): *metal and POP concentrations in subsistence foods, elemental composition of human tissue or blood, organics as indicators of bioaccumulation and transport, aerosol measurements, gas phase measures, animal tissue, plants and lichen composition*

Question 13: How do changes in terrestrial carbon storage and altered nutrient, carbon and sediment export influence aquatic ecosystems?
Attribute (Component/Process): *nutrient and carbon inputs, outputs and losses into streams and lakes*

Question 14: What are the key landscape features that control nutrient flux at multiple spatial and temporal scales?
Attribute (Component/Process): *effects of topography, soil parent material, geomorphology*

III. Landscape Processes in the Arctic Parklands

Question 1: How are glaciers responding to climate change in ARCN parks?
Attribute (Component/Process): *snowfall, glacial extent and area, thickness and surface elevation*

Question 2: How is climate change affecting the distribution and characteristics of ice patches? What archaeological and paleoecological materials are present?
Attribute (Component/Process): *Ice patch size and area extent, exposed organic materials (basal debris zone yields perishable resources, macrofossils, dung)*

Question 3: What is the depth, phenology, and distribution of snow pack in ARCN parks? What controls (precipitation, wind, weather patterns, etc.) the depth, phenology and distribution of snow pack in ARCN parks?
Attribute (Component/Process): *snow pack, depth, aerial extent, distribution, phenology, hardness and structure of ice layers*

Question 4: What controls climate and how is it changing in ARCN parks?
Attribute (Component/Process): *cloud cover, temperature, precipitation, active layer, basic components, storm tracks*

Question 5: Are there spatial and temporal changes in permafrost?
Attribute (Component/Process): *depth to permafrost, susceptibility, surface topography/thermokarst/thermal erosion, soil temperature, surface icings, changes to thaw lakes*

Question 6: What are the changes in distribution, characteristics, and frequency of solifluction, landslides, and debris flows?
Attribute (Component/Process): *landcover change, erosion, active layer monitoring*

Question 7: What is the distribution of vegetation across the landscape and how is it changing?
Attribute (Component/Process): *physiognomy, biomass, phenology, community assemblages and distribution, forest cover, alder cover, shrub height, lichen cover, species composition, community cover, riparian zones*

Question 8: Where do we find rare habitats and associated plant communities? What factors limit these plant communities?
Attribute (Component/Process): *community composition, rare or unusual substrate, hot or warm springs, threatened habitats, occurrence and distribution of rare habitats*

Question 9: What is the fire regime in ARCN parks and is it changing?
Attribute (Component/Process): *extent of area burned, timing of burn, frequency of burn, severity, land cover type, post-fire succession, fire suppression effects, exotics, fire management regimes, distribution and timing of lightning strikes*

Question 10: How do plant communities differ between different bedrock types?
Attribute (Component/Process): *substrate/bedrock, slope stability*

Question 12: How is changing landcover affecting the distribution and characteristics of ecosystems?
Attribute (Component/Process): *timing of break up and freeze up, channel dynamics, wetlands, thermokarst, lake levels*

Question 13: How are hydrologic regimes changing? Are stream floodplain interactions changing?
Attribute (Component/Process): *flow characteristics, discharge, floodplain dynamics, siltation*

Question 14: How is forest distribution changing?
Attribute (Component/Process): *treeline; forest cover, density, and species composition; reproduction; herbivory and disease; fire regime*

Question 15: How does the distribution of glacial deposits affect plant communities and how do they respond to change?
Attribute (Component/Process): *surficial geology, soil parent material, landscape age, plant communities, soil development*

Question 16: How will atmospheric contaminants affect plant community distribution and composition?
Attribute (Component/Process): *sphagnum, metals, sulfates, nitrates, dust*

Question 17: What does the paleorecord reveal about previous climate change?
Attribute (Component/Process): pollen records, glacier fluctuation, macro-fossils, sediment records, peat stratigraphy, bluff exposures, middens, unique paleontological resources

Question 18: Is permafrost degrading in ARCN parks in response to changing climatic conditions?
Attribute (Component/Process): depth to permafrost, active layer thickness, soil temperatures, permafrost temperature

IV. Migratory and Invasive Species of ARCN Parklands

Question 1: How is the composition and relative abundance of small mammals changing over time?
Attribute (Component/Process): small and meso mammal abundance, community composition

Question 2: Is the timing of migration changing?
Attribute (Component/Process): migratory mammals, migratory birds

Question 3: Is the distribution of migratory species changing over time?
Attribute (Component/Process): migratory mammals, migratory birds

Question 4: Has the phenology of vegetation development changed?
Attribute (Component/Process): vegetation phenology

Question 5: How has the composition of the vegetation changed?
Attribute (Component/Process): plant community composition

Question 6: How is the abundance, distribution, and timing of migration changing?
Attribute (Component/Process): species abundance and distribution

Question 7: How is the distribution of invasive species changing?
Attribute (Component/Process): species distribution and abundance

Question 8: What is controlling the range expansion of key species?
Attribute (Component/Process): muskox, moose, ravens, alder, coyotes, white spruce, beaver

Question 9: How are subsistence resources changing over time?
Attribute (Component/Process): Dall's sheep, fish (pike, whitefish, burbot), carnivores, berries, caribou, waterfowl, fur bearers, roots, black bear, ground squirrels

Summary of Past, Present, and Planned Future Monitoring Activities in ARCN

No task could be more important to developing a monitoring program than a thorough review of existing literature and prior inventory and monitoring efforts. The Arctic Network has made progress in assembling a knowledge base that will be valuable in designing a monitoring plan. Our data mining efforts have focused on two fronts: assembling a natural resource bibliography and identifying sources of high-quality inventory and monitoring data and collaborations. In 2004 we made great progress on populating the national Inventory and Monitoring bibliography, NatureBib, with publications about the arctic parks ecosystem. This effort has yielded thousands of references that will be a significant resource on the arctic biome. We also began data mining efforts with the goal of identifying present and historical resource inventories and monitoring efforts. While this effort is just getting started, we expect it will continue through the life of the program. Thus far, we have made a preliminary list of agencies, programs, existing ecological inventories and long-term studies that may be of value to the Arctic Network. This list is not exhaustive but highlights prominent, large-scale, and relevant data resources. The matrix shown below also hints at significant data gaps for the Arctic Network. We expect to expand this list considerably in the latter half of 2005.

Details about the datasets used to generate the matrix in Table 4 are described in Appendix 10, including their administrative agency, website URL, data categories, level two vital sign designation, and a summary.

Table 4. Summary of counts of major inventory and monitoring efforts in the Arctic Network of parks.

Category	BELA	CAKR	GAAR	KOVA	NOAT
Air Chemistry	1	1			
Amphibians	1	1	1	1	1
At-Risk Populations/Biota	1	1			
Baseline/Long-Term Plots					
Biodiversity	2	2	2	2	2
Biogeochemical Processes	1				
Birds	5	5	5	5	5
Climate/Weather/Climate Change	3	2	3	2	3
Contaminants	1	2			
Disease/Parasites	1	1	1	1	1
Disturbance/Fragmentation					
Fire	3	2	3	3	3
Fish	3	3	3	3	3
Food Webs/Trophic Interactions					
Fungi					
Geology	1	1			
Geomorphology/Landform Processes					
GIS datasets	1	1	1	1	1
Glacial Features and Processes					
Groundwater Dynamics					
Hillslope Features and Processes					
Human Use Activities (Subsistance,	1				
Ice Processes & Dynamics, & Snow					
Invasive Species	1	1	1	1	1
Invertebrates					
Lagoons					
Lake Features & Processes	2	2	2	2	2
Land Use/Landcover Change	6	7	4	6	4
Large Mammals	4	5	5	4	5
Management Concern	3	3	2	2	2
Marine Features and Processes					
Marine Hydrology					
Marine Mammals					
Microorganisms/Microbes					
Non-Vascular Plants					
Nutrient Dynamics/Cycling					
Paleoecology & Paleontology					
Permafrost					
Phenology					
Primary Production					
Remote Sensing					
Small Mammals	3	3	3	3	3
Soils (Chemistry, Erosion)	1	3			
Stream/River Channel Characteristics	2	2	2	2	2
Surface Water Dynamics					
Vascular Plants	2	2	3	2	3
Vegetation (general)	3	4	3	3	3
Visitor Usage					
Water Quality/Biota/Chemistry	1	1	1	2	1
Wetland (Distribution and Abundance)	3	3	3	4	3
Windblown Features and Processes	1				

Summary of Joint Arctic Initiatives of Importance to ARCN

Much of the knowledge of how arctic terrestrial and aquatic ecosystems respond to change has been generated at large, long-term research stations that facilitate multi- and interdisciplinary science (e.g., Toolik Lake Long Term Ecological Research Site). As the Arctic continues to undergo dramatic changes in climate and human land use, there is a paramount need to further understand how arctic ecosystems outside these long-term research stations will be impacted and how these changes will influence the future state of the Arctic and Earth systems. Many integrated monitoring and research networks are already in place or under development throughout the Arctic. Throughout the last decade, there have been a number of major international research and monitoring initiatives of significance to ARCN. In order for ARCN to develop a successful monitoring program, participation in national and international initiatives will be of the utmost importance (e.g., International Polar Year; High Latitude Ecological Observatory Network or HLEO-NEON). Below is a partial list of some of the most significant science initiatives taking place in the Arctic.

Alaska Satellite Facility
http://www.asf.alaska.edu/index.html

The Alaska Satellite Facility, located in the Geophysical Institute at the University of Alaska Fairbanks, downlinks, processes, archives, and distributes SAR data from the European Space Agency's ERS-1 and ERS-2 satellites, NASA's JERS-1 satellite, and the Canadian Space Agency's RADARSAT-1 satellite.

Available SAR products include full-resolution (25 m) images; low-resolution (240 m) images; complex-format SAR data products that retain amplitude and phase information, geocoded images, and uncorrelated (raw signal) SAR data, representing the original backscattered radar signals. ASF is one of several Distributed Active Archive Centers (DAACs) sponsored by NASA as part of the Earth Observing System initiative.

Arctic Alive! Online Educational Program
http://www.arcus.org/ArcticAlive/index.html

Arctic Alive! is a distance-learning environment for learners to be transported virtually to unique and remote locations within the arctic region. Arctic Alive! is not an information Internet site but an interactive, real-time, and unique web-based education program. It uses a variety of delivery methods and e-learning strategies to deliver arctic research to the classroom.

Arctic Climate Impact Assessment (ACIA)
http://www.acia.uaf.edu/

An international project of the Arctic Council and the International Arctic Science Committee (IASC) to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. The results of the assessment were released at the ACIA International Scientific Symposium held in Reykjavik, Iceland, in November 2004.

Arctic Coastal Dynamics (ACD)
http://www.awi-potsdam.de/www-pot/geo/acd.html

The Arctic Coastal Dynamics program is a multidisciplinary, multinational forum to exchange ideas and information. The overall objective of ACD is to improve our understanding of circum-Arctic coastal dynamics as a function of environmental forcing, coastal geology and cryology, and morphodynamic behavior.

Arctic Environmental Observatory (AEO)
http://arctic.bio.utk.edu/AEO/

An Arctic Environmental Observatory in Bering Strait, funded with support from the National Science Foundation, is a cooperative research project involving scientists Lee Cooper and Jackie Grebmeier of the University of Tennessee, Gay Sheffield of the Alaska Department of Fish and Game, and Lou Codispoti of the University of Maryland. Additional logistical assistance and support has been provided by the city of Diomede, local residents of Diomede, staff of the Bering Strait School District, and the U.S. and Canadian Coast Guards.

Arctic Logistics Information and Support (ALIAS)
http://www.arcus.org/ALIAS/index.html

ALIAS is a primary access point and a comprehensive information source to help researchers to assess the feasibility of working in a specific area; plan the conduct of research; view current research in a given area, including maps and publications; and make useful scientific and logistics support contacts.

Arctic Paleo-River Discharge (APARD)
http://www.awi-bremerhaven.de/GEO/APARD/

During the Arctic Ocean Science Board (AOSB) meeting held in Helsinki, 17-19 April 1996, it was recognized that freshwater input to and freshwater balance in the Arctic and its (paleo-) environmental significance have been identified as being of high priority to many institutions active in arctic oceanographical, chemical, biological, and geological research. Despite the importance of the Arctic Ocean river discharge on the global climate system and these international projects and programs partly dealing with paleo-river discharge, there is no comprehensive multidisciplinary and international research program on circum-Arctic river discharge and its change through time. Thus, it was decided to convene a series of international, multidisciplinary workshop on Arctic Paleo-River Discharge (APARD). The results of the first APARD Workshop were summarized in a draft and outlined the major scientific objectives and linkages to other international research programs dealing with arctic river discharge. The final APARD program was presented and accepted as an official AOSB program.

Arctic Region Supercomputing Center (ARSC)
http://www.arsc.edu/

The mission of the Arctic Region Supercomputing Center is to support high performance computational research in science and engineering with an emphasis on high latitudes and the Arctic. ARSC provides high performance computational, visualization, networking and data storage resources for researchers within the Department of Defense, the University of Alaska, other academic and scientific institutions, and government agencies.

Arctic Studies Center, National Museum of Natural History, Smithsonian Institution
http://www.mnh.si.edu/arctic/

The Arctic Studies Center, established in 1988, is the only U.S. government program with a special focus on northern cultural research and education. In keeping with this mandate, the Arctic Studies Center specifically studies northern peoples, exploring history, archaeology, social change, and human lifeways across the circumpolar world. The center is part of the Department of Anthropology, in the National Museum of Natural History, a section of the Smithsonian Institution. Having pursued northern studies since the 1850s, the Smithsonian possesses one of the world's finest anthropological collections from arctic and subarctic regions.

Arctic System Science (ARCSS) Data Coordination Center
http://arcss.colorado.edu/

The Arctic System Science (ARCSS) Data Coordination Center (ADCC) at the National Snow and Ice Data Center, University of Colorado at Boulder, is the permanent data archive for all components of the ARCSS Program. Funded by the National Science Foundation's Office of Polar Programs, the focus of the center is to archive and provide access to ARCSS-funded data.

Barrow Arctic Science Consortium (BASC)
http://www.sfos.uaf.edu/basc/

The Barrow Arctic Science Consortium is dedicated to the encouragement of research and educational activities pertaining to Alaska's North Slope, the adjacent portions of the Arctic Ocean, and in Chukotka, Russia. A cooperative agreement between BASC and the National Science Foundation's Office of Polar Programs provides funding for BASC's activities.

Bering Climate and Ecosystem
http://www.beringclimate.noaa.gov/

There is an explosion of interest in Northern Hemisphere climate, and new science programs are highlighting the importance of recent changes in the Arctic on mid-latitude climate impacts. The Bering Sea is one of the world's major fisheries, and Alaskan waters provide half of the landed U.S. catch of fish and shellfish. Because of the changes going on in the Arctic, future evolution of the Bering Sea climate/ecosystem is more uncertain. This website presents the current Bering Sea status, a quick data summary, and the main set of time series that form the basis of a smaller set of Bering climate and ecosystem indices.

Center for Global Change and Arctic System Research
http://www.cgc.uaf.edu/

The Center for Global Change is organized under the International Arctic Research Center (IARC) at the University of Alaska Fairbanks (UAF). A board of directors made up of UAF institute directors and deans guides the center's institutional directions and facilitates the cooperation and coordination of the university community. The center has a science steering committee made up of faculty from a wide range of disciplines. This steering committee provides leadership in developing mechanisms to provide and enhance interdisciplinary research and education.

Coastal Alaska Observing System (CAOS)
http://halibut.ims.uaf.edu:8000/SALMON/caos_signup.php

An effort to develop a nationwide backbone for an integrated, sustained ocean observing system is being spearheaded by Ocean.US. Ocean.US is working with Congress and the White House to develop the rationale for and also develop the basic components of such a system. At the national level, Ocean.US is seeking sustained funding for the backbone (see relevant section of the Energy Policy Act of 2002). The backbone will consist of regional observing systems that will address national issues.

Cooperative Institute for Arctic Research (CIFAR)
http://www.cifar.uaf.edu/

CIFAR, established in May 1994, promotes research collaboration between the National Oceanic and Atmospheric Administration (NOAA) and the University of Alaska Fairbanks, as well as other agencies and institutions involved in arctic research.

High Latitude Ecosystems Directorate
http://www.mabnet.org/directorates/highlat.html

Special emphasis has been placed on the high-latitude regions of the Earth as potentially responding earliest to effects of global climate change. These regions include the zones of continuous and discontinuous permafrost and some of the most undeveloped land areas of the Northern Hemisphere. They support indigenous human populations that until very recently have practiced a subsistence-based economy and lifestyle. Now these regions are undergoing rapidly accelerating social change, including increased pressure for resource extraction and growing resident populations. These changes have increased scrutiny of resource use and management.

Institute of Arctic and Alpine Research (INSTAAR)
http://instaar.colorado.edu/

The Institute of Arctic and Alpine Research (INSTAAR) strives for excellence in research, education, and outreach related to Earth system science and global change in high-latitude, alpine, and other environments. INSTAAR is located at the University of Colorado within the graduate school and affiliated with the departments of Anthropology, CEA Engineering, Environmental Studies, Ecology and Evolutionary Biology, Geography, Geological Sciences, and Atmospheric and Oceanic Sciences (PAOS).

International Arctic Science Committee (IASC)
http://www.iasc.no/

The International Arctic Science Committee is a nongovernmental organization whose aim is to encourage and facilitate cooperation in all aspects of arctic research in all countries engaged in arctic research and in all areas of the arctic region.

Long Term Ecological Research (LTER)
http://www.lternet.edu/

The Long Term Ecological Research network is a collaborative effort involving more than 1,800 scientists and students investigating ecological processes over long temporal and broad spatial scales. The network promotes synthesis and comparative research across sites and ecosystems and among other related national and international research programs. The National Science Foundation established the LTER program in 1980 to support research on long-term ecological phenomena in the United States. The 26 LTER sites represent diverse ecosystems and research emphases. The LTER Network Office coordinates communication, network publications, and research-planning activities.

Paleoenvironmental Atlas of Beringia
http://www.ncdc.noaa.gov/paleo/parcs/atlas/beringia/

This World Wide Web site provides historical and geologic information on past climates and environments in Beringia (northwestern North America and northeastern Asia). The site provides basic data (e.g., the original geologic data from individual sites), summaries, and syntheses of the basic data presented in map and/or time-series form. The site is a living scientific document, and syntheses contained within it are synthesized from the data archived in the atlas database. It grows as new data and syntheses become available. The site is intended as a resource for both the global change scientific community and students who wish to learn more about the history of the arctic environment. An additional section for the general public is under construction. See the future directions section for more information about planned sections of the atlas.

Study of Environmental Arctic Change (SEARCH)
http://www.arcus.org/SEARCH/index.php

SEARCH is an interagency effort to understand the nature, extent, and future development of the system-scale change presently seen in the Arctic.

U.S. Arctic Research Commission
http://www.arctic.gov/

The United States Arctic Research Commission was established by the Arctic Research and Policy Act of 1984 (as amended, Public Law 101-609). The commission's principal duties are (1) to establish the national policy, priorities, and goals necessary to construct a federal program plan for basic and applied scientific research with respect to the Arctic, including natural resources and materials; physical, biological, and health sciences; and social and behavioral sciences; (2) to promote arctic research, to recommend arctic research policy, and to communicate our research and policy recommendations to the president and Congress; (3) to work with the National Science Foundation as the lead agency responsible for implementing arctic research policy and to support cooperation and collaboration throughout the federal government; (4) to give guidance to the Interagency Arctic Research Policy Committee (IARPC) to develop national arctic research projects and a five-year plan to implement those projects; and (5) to interact with Arctic residents, international arctic research programs and organizations and local institutions, including regional governments in order to obtain the broadest possible view of arctic research needs.

U.S. Man and the Biosphere Program
http://www.mabnet.org/

The U.S. Man and the Biosphere Program is an interdisciplinary research effort directed toward providing information for the solution of natural resources and environmental issues. As an intergovernmental program, MAB presents an opportunity for international cooperation and a focus for the coordination of related programs aimed at improving the management of natural resources and the environment.

U.S. National Science Foundation, Office of Polar Programs (OPP)
http://www.nsf.gov/dir/index.jsp?org=OPP

The Office of Polar Programs (OPP) manages and initiates National Science Foundation funding for basic research and its operational support in the Arctic and the Antarctic. The funds are provided as NSF grants to institutions (mainly U.S. universities), whose scientists perform the research at the institutions or in a polar region, and as cooperative agreements or contracts to support organizations, including contractors and the U.S. military.

Chapter 2
Conceptual Models

"Everything should be made as simple as possible, but not one bit simpler."

Albert Einstein

Introduction: Framework for Conceptual Model Development

Conceptual ecosystem models are an excellent way to convey information about complex ecosystems to resource managers and the public. Conceptual models can also be used to help describe our current understanding of anthropogenic sources of disturbance to those ecosystems and the processes or components of the ecosystem impacted by that disturbance (Jenkins et al. 2003). Conceptual models should: (1) describe our current understanding of system components and processes, (2) identify linkages and interactions between those components, and (3) identify gaps in our knowledge (Gross 2003).

Early in the process of developing a monitoring program, visual models provide a framework for discussing the ecosystems of interest. While the National Park Service's Monitoring Program "does not intend to develop quantitative ecosystem models or dictate management policy, constructing a set of realistic, focused conceptual models is an important starting point for designing effective management policies" (Gross 2003). To this end, ARCN developed several 3-D landscape-scale ecosystem models that describe key features and processes within the ARCN parks. In some cases, additional descriptive models were developed in order to highlight unique ecosystems of interest (e.g., arctic lagoons, spring streams) and provide additional details about key ecosystem processes or components of interest. A series of nested models describing current and future threats to ARCN ecosystems and potential consequences of those threats is also presented. Special areas of management concern for ARCN parklands (e.g., global climate change, air toxins, invasive species) are also addressed using conceptual models.

The Arctic Network Strategy for Conceptual Model Development

The Arctic Network held three scoping workshops, which were designed, in part, to help network staff develop a set of conceptual models of the natural and anthropogenic features and processes of the enormous areas included in the parks. Each of the three workshops tackled one of three areas of interest to ARCN: freshwater, coastal-influenced, and terrestrial ecosystems. Workshop participants received a workshop notebook before each of the scoping workshops. Before attending the workshops, technical committee members and outside experts attending each of the meetings were asked to either create models in their area of expertise or comment on earlier versions of draft models. On day two of the workshops, participants split up into small working groups to further revise models. All hand-drawn draft models from each of the workshops were reproduced in a computer graphics program and placed in workshop output summary documents (see Appendices 4–6). Information from the workshops was then interpreted and summarized into 3-D landscape-scale conceptual ecosystem models. These models were included in the post-workshop output summary documents. The output documents were placed on the ARCN website for workshop participants to review. Models were revised where appropriate. A subset of these models appear in this chapter.

Our hope is that the models will (1) help to describe the complex ecosystems of ARCN; (2) elucidate current and potential anthropogenic stressors to ARCN ecosystems, (3) suggest potential mechanisms by which these anthropogenic stressors could impact ARCN ecosystems, and (4) help lay the foundation for monitoring critical aspects of the environment of the parks.

Just as ecosystems are fundamentally dynamic, so should be the conceptual models that describe them. For this reason, the conceptual models presented in this chapter reflect only our current understanding of ecosystem dynamics and as such are works in progress.

Conceptual Models and the Issue of Scale

Conceptual models should demonstrate the linkages between environmental stressors, ecosystem components, and expected consequences to that system (Figure 9; Thornton et al. 1993, Noon 2003). However, this approach is problematic because the boundaries between spatial, temporal, and ecological scale are indistinguishable in nature (O'Neill et al. 1986). Therefore all models are an artificial representation of reality as continuous phenomena are dissected into discrete categories.

A successful monitoring program must be based on a solid understanding of the cumulative processes responsible for driving change and the spatial and temporal scale at which this change is reflected in the ecosystem of interest. In addition, if the wrong ecosystem indicator or vital sign is selected or monitored at an inappropriate temporal or spatial scale, the inference from stressor to ecosystem consequence may be wrong (Figure 9).

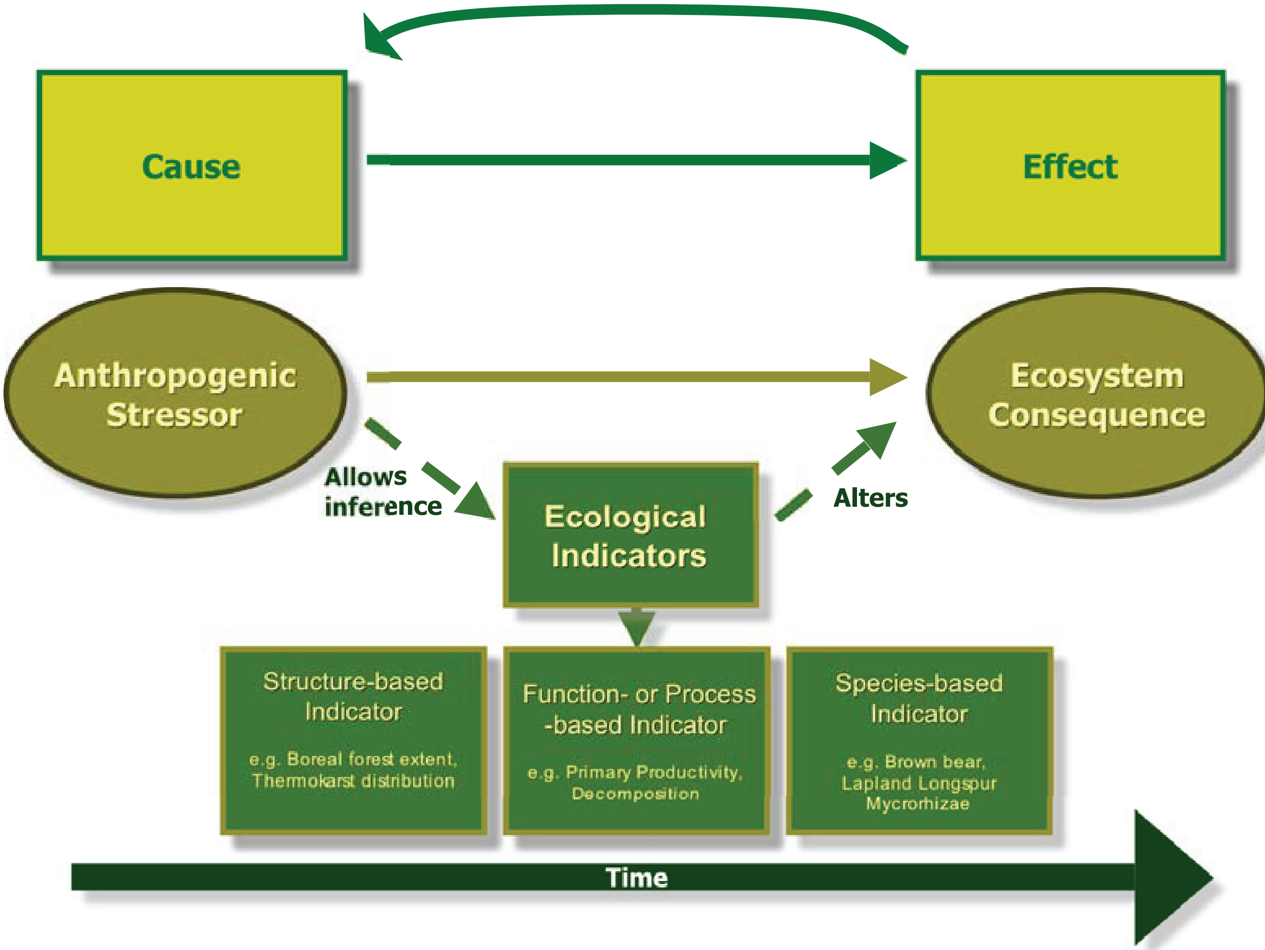


Figure 9: Simplified model showing the NPS approach to monitoring and the emphasis on indicators or "vital signs," which should represent the cumulative effects of environmental degradation to ecosystems of interest. Redrawn and revised from Noon 2003.

Spatial Scale

Monitoring can usefully occur in situations as geographically limited as a single thaw pond, mountain slope, or heavily used fishing location. It is likely to be most useful if observations on this scale are incorporated into a broader perspective. In a sense, all larger scale monitoring plans are composed of local sampling schemes, with information obtained, collected, and interpreted to provide a broader picture. Not only does monitoring within the parks in our study area provide information on the condition of the park itself, but it may also be highly significant on a scale as large as the whole circumpolar north. Thus, while the primary function of long-term monitoring may be seen as providing useful information to be used in managing parks, or areas within parks, we should not lose sight of the potential for NPS-sponsored monitoring to affect our overall understanding of the northern environment. At the same time, it needs to be recognized that many of the changes that appear as local phenomena within the parks are, in fact, manifestations of much larger scale events that are expressed in a wide variety of ways over broad areas of the earth.

Although the ARCN Monitoring Program will focus on ecosystems found within the park boundaries, it is important to realize that changes to park ecosystems may be manifestations of larger scale phenomena (Figure 10). For this reason, collaboration amongst scientific peers working in other disciplines (e.g., anthropologists studying cultural dynamics or economic changes in local villages; earth system scientists studying the global water balance and its implications for arctic ocean circulation) will be crucial in laying the foundation for any long-term monitoring program in the Arctic. To this end, many circumpolar initiatives have or are being proposed for monitoring in the Arctic (see Chapter 1).

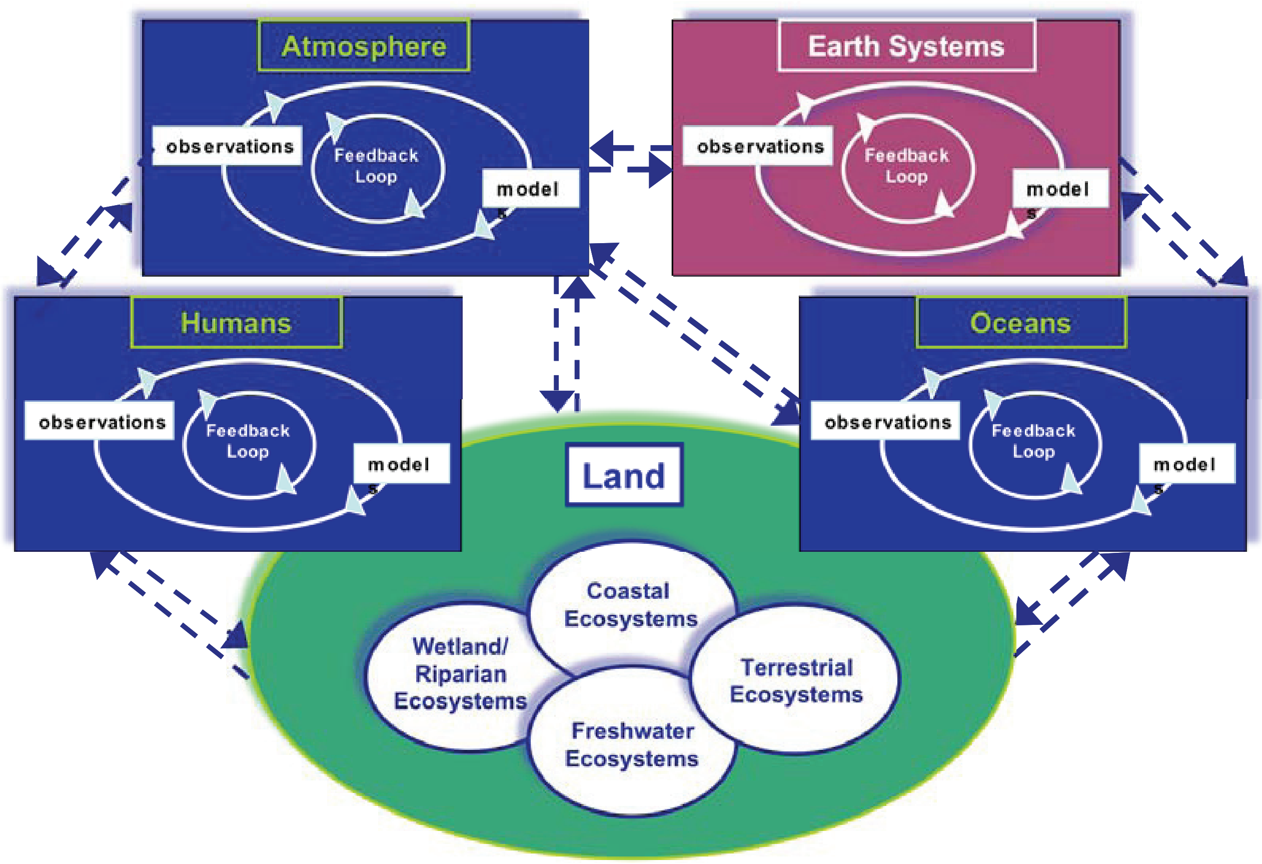


Figure 10: Although the ARCN Monitoring Program will focus on ecosystems found within the park boundaries (the "land" portion of this diagram) it is important to realize that changes to park ecosystems may be manifestations of larger scale phenomena occurring in the circumpolar north or world in general. For this reason, collaboration amongst scientific peers working in other disciplines will be crucial in laying the foundation for any long-term monitoring program in the Arctic. (Figure modified from Hinzman and Vörösmarty 2001).

Finding an Appropriate Scale to Consider Anthropogenic Stressors in the Arctic

Human impacts to ARCN come at varying spatial scales. At the largest spatial scale, national and international politics, laws, and treaties could have an impact on arctic ecosystems (Figure 11). Although NPS may not have the resources or staff to directly affect legislation or treaty status, these global stressors must be considered when thinking about how arctic ecosystems might be changing. For example, it should be acknowledged that persistent organic pollutants (POPS), which are accumulating in the Arctic, their final repository, are coming from other parts of the world. The presence of these pollutants could be having an effect on the fecundity, reproduction, and survivorship of large mammal species living in arctic ecosystems (Arctic Monitoring and Assessment Programme 1997, Jepson et al. 1999, Wiig et al. 1998). A large suite of human activities in the circumpolar arctic may also have a direct impact on ARCN ecosystems (Figure 12). For example, circumpolar feedbacks caused by human-induced climate change and its effect on arctic sea thickness and extent could have an impact on weather and climate in arctic ecosystems. This, in turn, could have an impact on the coastal ecosystems of ARCN and local subsistence practices (Figure 13). Local anthropogenic stressors within or adjacent to ARCN park boundaries could also have a direct impact on ARCN ecosystems (Figure 14). For example, the cumulative effects of oil and gas development on the North Slope could directly impact ARCN ecosystems in a variety of ways (National Research Council 2003). Possible ecosystem responses of anthropogenic impacts include things like changes in disturbance regime (increased fire), physical shifts in the landscape (e.g., thermokarst formation), decreases in ecosystem stability and resilience (decrease in biodiversity), or population shifts of certain species (e.g., invasive species).

Time Scale and Monitoring in ARCN

Northern and western Alaska, perhaps even more than most regions of the world, have undergone enormous changes in the relatively recent geological past. In order to understand both the current array of organisms and the processes that maintain their interactions with the environment, it is necessary to approach them with a historical perspective in mind (Figure 15). In particular, we must recognize that the current environmental situation results from the interaction of processes that take place over greatly varying time scales. For purposes of discussion, we suggest the following time scales:

Long-term geological: dealing with events that have occurred over millions of years, such as mountain building, the distribution of certain substrates, etc.

Late Quaternary: changes that have been important in the late Pleistocene and Holocene, especially the roughly 20,000 years since the last glacial maximum. These would include the termination of continental glaciation over much of the Northern Hemisphere, the submergence of huge areas of continental shelf (especially the Bering Land Bridge), the extinction of many important megafaunal species, and the earliest activities of humans within our area.

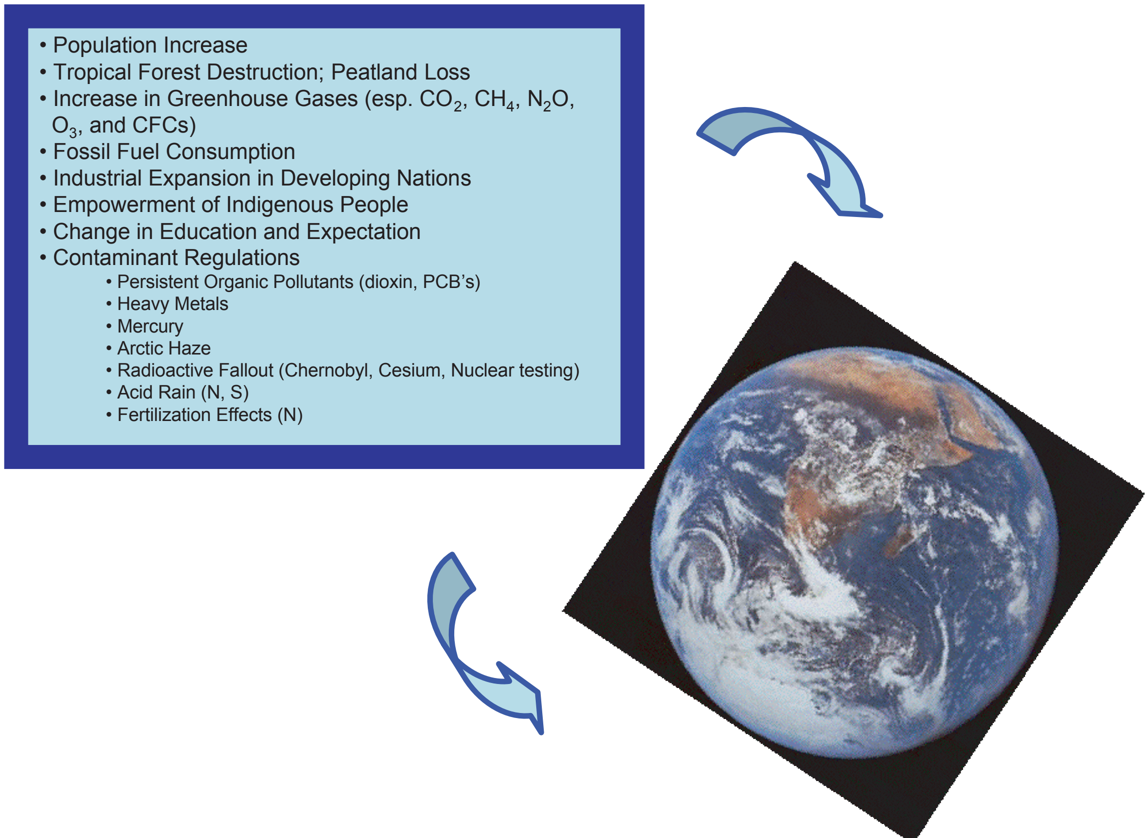


Figure 11: Global anthropogenic stressors/drivers to ARCN ecosystems.

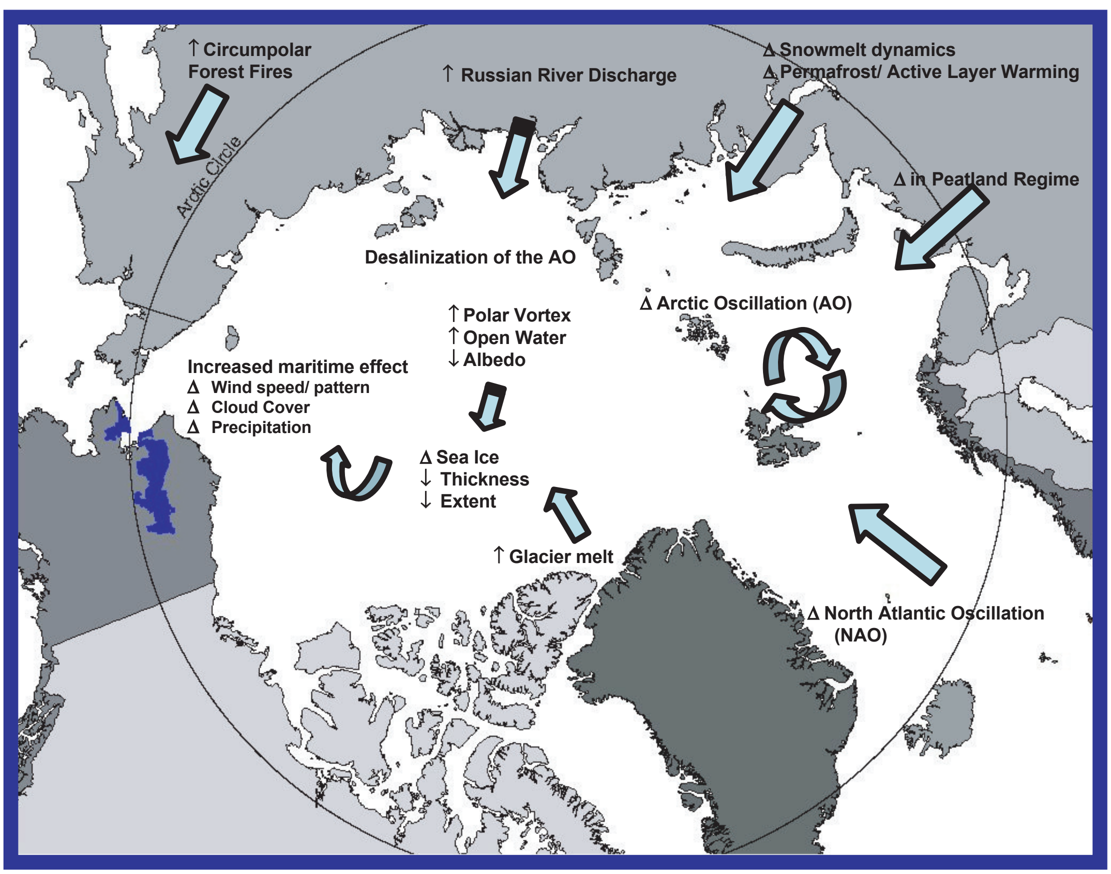


Figure 12: Circumpolar anthropogenic stressors/drivers to ARCN ecosystems.

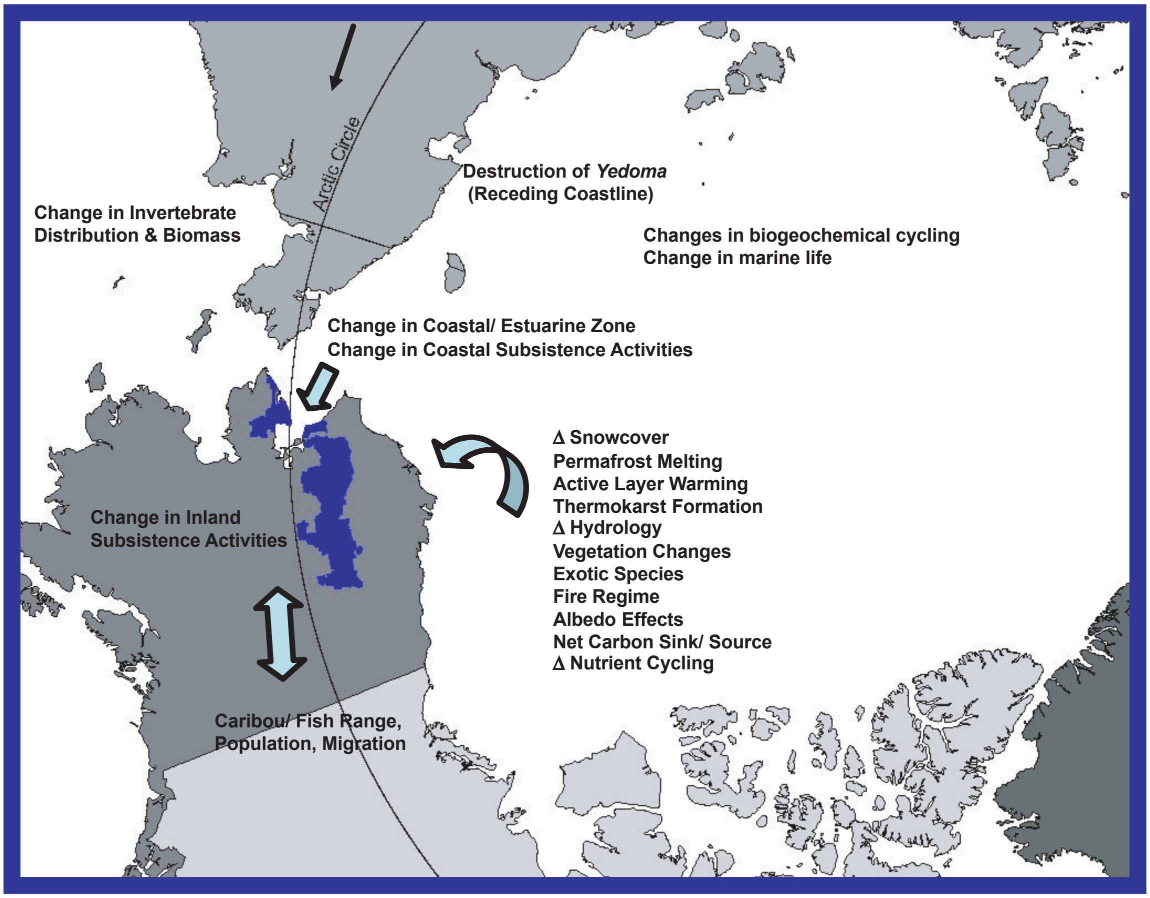


Figure 13: Regional anthropogenic stressors/drivers to ARCN ecosystems.

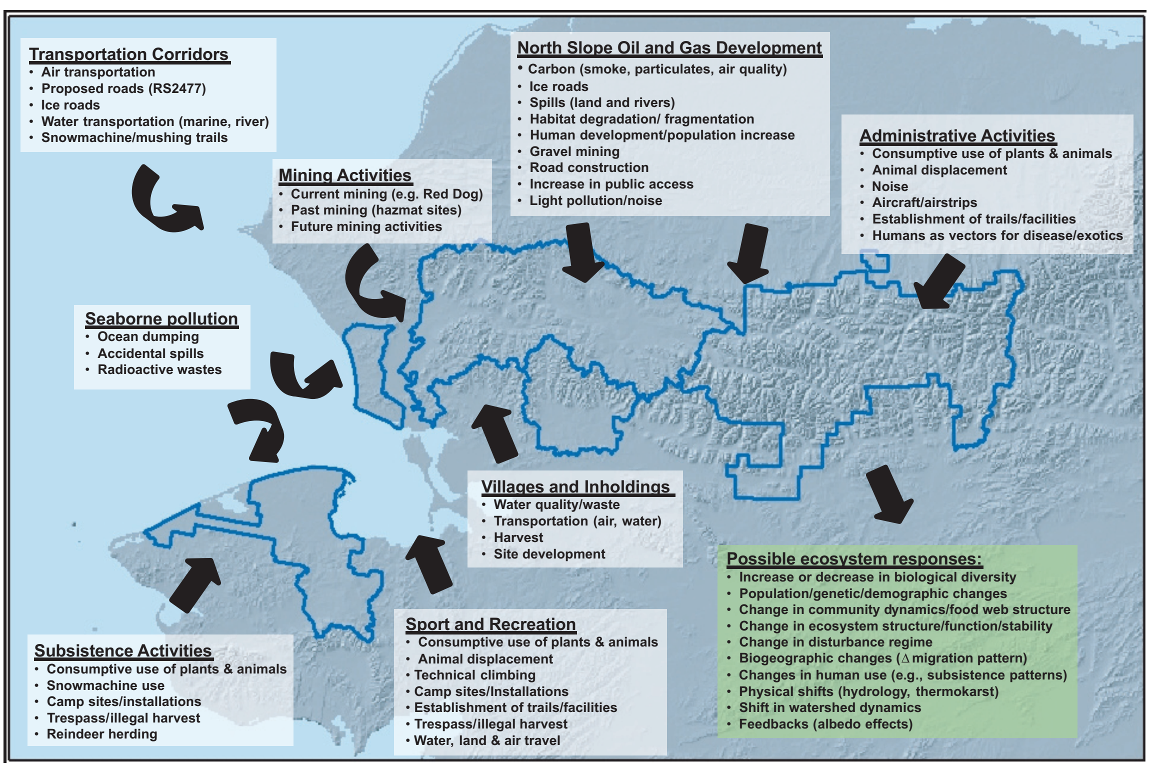


Figure 14: Regional anthropogenic stressors/drivers to ARCN ecosystems (within or adjacent to park boundaries).

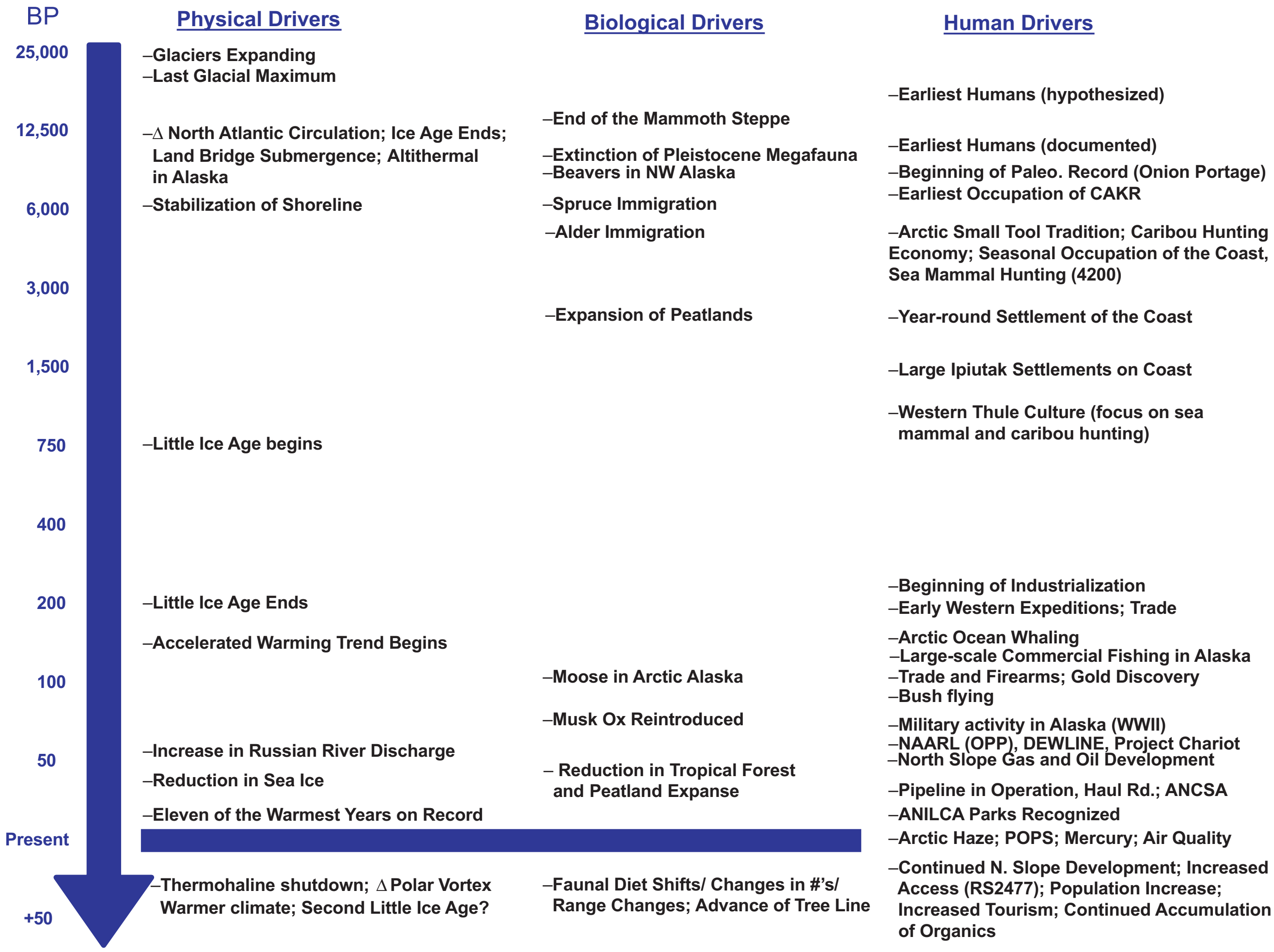


Figure 15: Significant physical, biological, and human drivers in the Arctic in the last 25,000 years before present.

Early-mid Holocene: changes primarily in vegetation and fauna associated with the emergence of modern ecosystems. Beginning of establishment of modern coastal features, such as the beach ridges of Cape Krusenstern and Cape Espenberg. Stabilization of many terrestrial features such as dunes and loess deposits.

Prehistoric: the emergence of the ancestors of the indigenous cultures of the area and the increasing importance of archaeological sites and materials as sources of data on the nature of the environment.

Historic-current: the time including the influence of Western industrial society on the environments and peoples of our area, beginning soon after 1,800 C.E.

Short term: many of the phenomena with which we are concerned may be evident in the course of a very few years. They may be individual, recurrent, or cyclical.

Terrestrial Ecosystems of the Arctic Network

It is convenient, although not altogether precise, to divide the terrestrial ecosystems of ARCN into upland and lowland elements. Upland environments are characterized by extensive areas of exposed bedrock, shallow, unstable soils, steep slopes, and small, high-energy streams. Lowland areas have little relief, gentle slopes, often deep alluvial deposits, and, in our area, usually heavily permafrost and ice-rich soils and substrates. They often contain, or are associated with, large, slow-moving watercourses with extensive sandbars and other alluvial deposits. Upland (montane or alpine) situations may occur at almost any elevation within ARCN, since the traditional lower boundary for alpine regions, the treeline, is never more than 500 to 700 m above sea level. Much of ARCN lies beyond the arctic (latitudinal) treeline, so that even the lowlands are tundra covered and have many of the aspects of alpine situations in more temperate regions. The distinguishing features between uplands and lowlands, then, depend on the amount of relief and whether erosional or depositional processes dominate the landscape. It is possible to cross from upland to lowland environments within a few meters and with little or no elevation change, so much of ARCN is a complex mosaic of the two.

Figures 16 and 17 provide models of the array of landscapes and ecosystems generally associated with uplands and lowlands. They also show graphically the complex interrelationship between the two elements.

Mountain and Upland Ecosystems of ARCN

Upland ecosystems in ARCN are areas that contain higher elevations and moderate to high relief along with narrower and more sinuous river valleys (Figure 16).

Underlying geology is a key feature of the landscape to consider when thinking about ecosystem drivers within the arctic parks. The nature of the bedrock can affect or control the nature of the ecosystems in several ways. Exposed, resistant bedrock is often characterized by steep slopes and minimal soil development. Certain kinds of rock are often associated with particular geomorphic features. For example, granitic outcrops are often the basis for spectacular alpine features found in the Arrigetch Peaks and Mt. Igikpak regions in GAAR. In other areas, especially BELA, granite exposures are responsible for the formation of clusters of tors. Lava flows of comparatively recent age, such as are found widely in BELA, form extensive rocky barrens and are often associated with features such as Marr Lakes. The chemical nature of the underlying bedrock may also have a profound effect on the vegetation. This is particularly evident in the case of the extensive areas of limestone and other carbonate rocks, such as those found in CAKR and locally in the other parks.

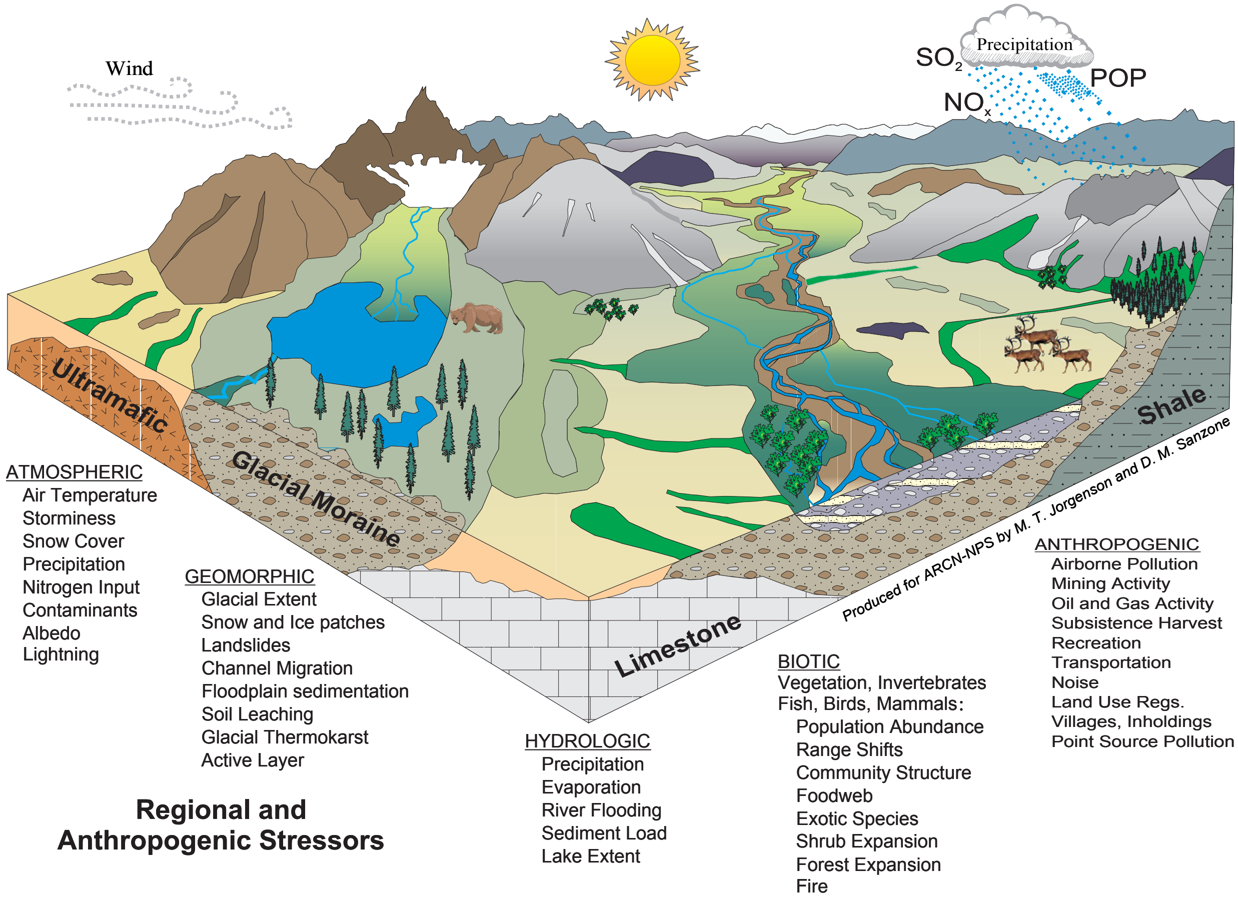


Figure 16. Mountain and upland ecosystems of ARCN and related anthropogenic stressors.

The steep slopes and high elevations characteristic of mountainous terrain provide the basis for many characteristic geomorphic features. Prominent among these are features associated with past and present glaciation. At various times during the earlier Pleistocene, a considerable portion of ARCN was covered by large ice sheets. However, during the latest glacial maximum, about 20,000 years ago, large glaciers were much more localized and occurred mainly in the central Brooks Range. Local glaciers did, however, expand far beyond their present limits in the western Brooks Range and the Seward Peninsula. Currently, glaciers are limited in extent and occur mainly in GAAR.

Aside from the tectonic processes that created the mountains, glacial action is the most significant geomorphic process in virtually all the montane areas in the cool temperate and polar regions. In ARCN, the major features of the landscape of GAAR are of glacial origin.

The more conspicuous geomorphic features of glaciated mountain regions are erosional: cirques, horns, and glacial valleys, for example. Glaciation also provides an array of depositional features, such as moraines and valley trains. Many of the features lying well beyond the mountain ranges, such as the rolling terrain of the middle Noatak Valley, are glacial deposits. Glacial action has also been the prime source of sediments for many of the stream deposits throughout much of ARCN. The shrinkage or disappearance of glaciers can remove the main source of sediments from streams and rivers.

Glaciers are uniquely sensitive to changing climate; they are important sources of data in climatic studies. While glaciers normally retreat during warming periods, warmer climates may, paradoxically, cause glaciers to expand because of increased snowfall. The presence of glaciers can have profound effects on stream hydrology, since maximum stream flow from glaciers occurs during warm, sunny periods of maximum melt, rather than times of high precipitation.

In addition to true glaciers, there are extensive areas of late-lying or perennial snow and ice in the mountainous regions of ARCN. These affect the environment in a number of ways: they provide moisture sources during dry periods in summer, and they often shorten the growing season to the extent they inhibit the presence of many forms of vegetation. Snowbeds and overflow ice (aufeis) fields are perhaps even more sensitive to climate change than are glaciers.

Periglacial phenomena are characteristic of unglaciated portions of cold regions; they include permafrost and a wide variety of features associated with intense freeze-thaw cycles. Some of the most complex phenomena associated with permafrost occur in deep, unconsolidated sediments on lowlands; they are treated in the next section. In montane environments, important periglacial phenomena involve frost wedging and cracking of bedrock and outcrops and boulders and various forms of mass wasting. Retreating glaciers leave oversteepened slopes on the sides and headwalls of empty cirques and valleys. Frost wedging of the steep walls results in deep and unstable deposits of debris at the bottom of cliffs and crags, and these are subject to landslides. Solifluction often occurs on vegetated slopes. This is the process by which soil creeps downslope in summer, when the top layer is unfrozen and saturated with meltwater.

In the mountainous regions of ARCN, vegetation communities range from the polar desert of the high, barren summits through various forms of alpine tundra, extensive brushlands, to, in the more inland areas, the upper reaches of boreal forest formed mainly of white spruce (*Picea glauca*). Polar desert communities in ARCN are similar in composition to that found in high arctic regions such as the northern Canadian Arctic Archipelago. Vascular plants are almost entirely herbaceous and mainly circumpolar species. Moss patches are extensively developed in moist areas. Much of the bare rock faces are heavily vegetated with lichens. Areas that are snow free for only a few weeks in late summer are sparsely vegetated.

Alpine tundra is a broad category; it includes a great variety of local forms of vegetation dominated by herbaceous plants and low shrubs. Some of the variation is associated with altitude, some with slope steepness and exposure, some with soil and substrate structure and chemistry, and some with moisture availability. The number of potential species available is high, and many of the rarer species of plants from our area are found in alpine tundra locations, where they may be locally abundant but widely separated from other colonies. Alpine tundra provides important foraging areas for large herbivores such as Dall's sheep (at higher elevations), caribou, and, where they occur, muskox. Some smaller herbivores, such as marmots, are largely confined to alpine tundra. Changes over time in alpine tundra tend to be subtle, and the relevance of the changes to broader scale events is usually difficult to understand. Some of the greatest diversity in alpine tundra species composition occurs in seepage areas, and these are usually related to late-lying snow beds, so changes in snow cover regime may be well correlated with changes in distribution and composition of certain alpine tundra communities. Alpine tundra generally becomes richer in shrubs at lower elevations and merges with shrubland. Alternatively, it may grade more or less imperceptibly into the tussock tundra and wet meadows characteristic of lowland tundra.

Shrubland is characteristic of the lower slopes of mountains throughout ARCN, but is especially well developed immediately above (or beyond) treeline in the Brooks Range. The species composition of shrubland varies widely but is often correlated with the direction of slope exposure. Cooler, moister slopes are generally dominated by dense alder (*Alnus crispa*) thickets. These may occur in other situations as well, especially on glacial moraines and outwash plains. Several species of willow (*Salix*) occur widely in shrubland, and the exact species compositions seems to depend on a variety of factors such as elevation, moisture availability, soil type, and slope stability.

Boreal forest is a minor component of the upland vegetation. Spruce stands are found along the lower reaches of some of the watercourses. Isolated individual trees are found in the lower reaches of brushland, where trees may be advancing. There has been a great deal of study of the advance and retreat of treeline over time in various parts of the north, and these studies provide important evidence for long-term climatic trends. In addition to spruce forest, there are often small stands of cottonwood (*Populus balsamifera* and *P. deltoides*) occurring well beyond or above the conifer treeline. In some areas there are also small riparian poplar woodlands. These may host outlying populations of species of insects and nesting birds that are otherwise typical of the boreal forest.

Arctic Lowland Ecosystems

Lowlands are generally areas of low relief and low elevation (Figure 17). Within ARCN we define them on the basis that their substrate is mainly the result of depositional factors. With the exception of recent lava flows within BELA, there is little exposed bedrock. As mentioned above, exposed bedrock in the form of isolated crags and tors creates a montane environment, even when they occur at low elevations.

The geomorphic features of lowland areas are generally the result of direct glacial deposition (moraine), alluvial deposits associated with streams, mass wasting downslope, and Aeolian deposits, most of which are now stabilized. Thus, most lowland ecosystems are developed on landscapes that feature deep deposits of unconsolidated material. Since the mean annual temperatures throughout ARCN are well below freezing, water contained in this material is usually frozen; most of ARCN lies within the zone of continuous permafrost. Although permafrost is defined as perennially frozen material, permafrosted landscapes developed on unconsolidated deposits are often quite dynamic. In addition to the active layer—the seasonally thawed soil above the permafrost—there are a number of situations in which freezing and thawing processes create major alterations and instabilities in permafrosted terrain. These include ice-wedge polygon formation and other types of processes that form patterned ground. Of particular interest are thermokarst processes. These are the result of the thawing of ice-rich frozen ground; they often result in soil slumps, the creation of ponds and migration of drainage channels, and the draining of older thaw lakes. Thermokarst processes are known to be increasingly active in many polar regions in recent decades.

Permafrost action is less conspicuous in active stream systems and in aeolian features. In these situations drainage is better, the active layer is deeper, and redeposition of materials by stream action tends to mask the more slowly acting permafrost processes. Sand and gravel bars cover large areas of the lowlands, as even small streams often carry heavy sediment loads during some seasons of the year. Aeolian features are currently mostly stable and covered with vegetation; the most conspicuous exceptions are the dune areas in the Kobuk Valley.

Climate, terrain, and vegetation strongly influence the occurrence, extent and severity of fires within the lowland ecosystems of the Arctic Network. The subarctic boreal forests and low arctic tundra biomes are subject to periodic fires. The frequency and extent of the fires is governed by vegetative, geographic, and climatic factors. One of the major uncertainties regarding the effects of climate change on terrestrial eco-

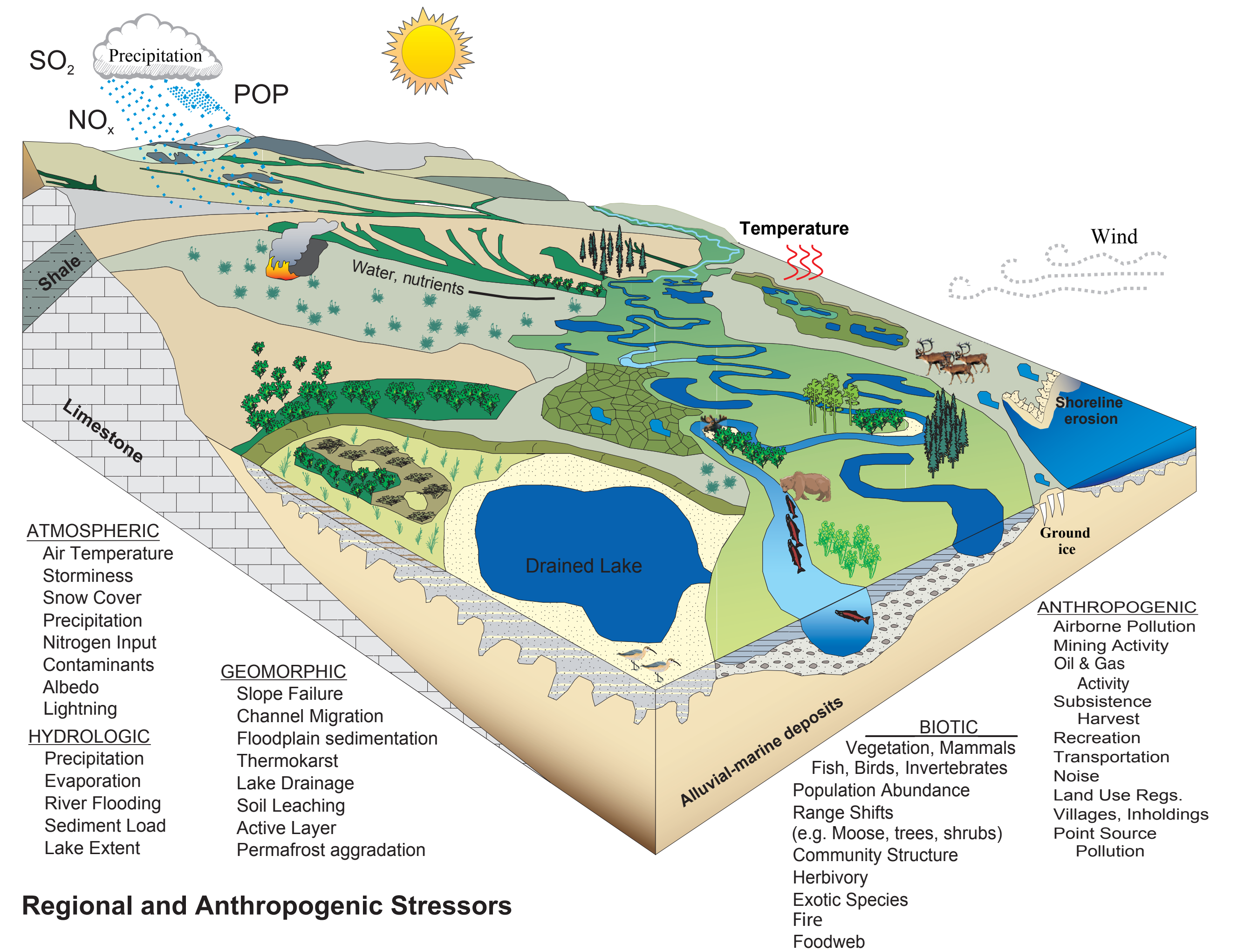


Figure 17: Arctic lowland ecosystems of ARCN.

systems in the Arctic is how warming will affect the extent and frequency of tundra and subarctic boreal forest wildfires and what effects such fire disturbance would have on these ecosystems. Tundra and taiga fires generally accelerate carbon loss due to both direct burning and subsequent warming of soils causing higher rates of decomposition.

Boreal forest covers broad areas of KOVA and GAAR, some parts of NOAT, and almost none of BELA and CAKR. The main component of the boreal forest is spruce (*Picea* spp.), and the distribution of this species is closely associated with temperatures during the growing season. The migration of spruce forest into the surrounding tundra areas is the subject of several current studies; the results generally indicate that this is occurring, although not in a uniform or entirely predictable fashion. The presence or absence of spruce forest is important for several reasons. Many vertebrate species are more or less dependent on spruce; these include red squirrels, spruce grouse, hare species, and Canadian lynx. Many invertebrates such as bark beetles are both dependent on spruce and can cause major mortality of the spruce forest, as has happened recently in southcentral Alaska. Spruce forest also affects the landscape in that it changes the albedo and reduces soil temperature by shading the ground surface and modifying snow accumulation.

Various kinds of brushland are widespread in the lowlands of ARCN. Many of these are willow thickets associated with streams and comprised of many species, often depending on such factors as stream size and bank stability. Other types of scrub vegetation involving willow species and dwarf birch (*Betula nana* and *B. glandulosa*) are widespread. Alder (*Alnus crispa*) stands are more common on slopes and moist valley sides, usually in the foothills of the mountains.

The most widespread type of vegetation in most lowland situations is sedge meadow. This is the main component of low arctic tundra in the region, and it generally consists of two types: wet meadows and tussock tundra. Tussock tundra covers enormous areas of rolling terrain, such as occurs throughout the middle Noatak drainage. Its dominant species is a cottongrass (*Eriophorum vaginatum*) which forms dense, peaty tussocks, each surrounded by a moist, shaded moat. These areas provide important habitat for caribou during much of the year. They are also populated by a wide array of small mammals, mainly microtine rodents and shrews.

Wet meadows are usually associated with flat, heavily permafrosted terrain. The vegetation consists largely of sedges and grasses. Water stands on these meadows during much of the year, and they form a transition between aquatic and terrestrial environments. Wet meadows are often the areas most profoundly affected by changes in the permafrost regime. These include natural cycles that tend to create and drain lakes and ponds, as well as anthropogenic changes. Many of the lowland areas have been extensively investigated for potential petroleum development; others have served as corridors for moving heavy equipment to mineral exploration sites. These activities often affect the tundra surface to such an extent that they cause changes in the permafrost regime, resulting in extensive anthropogenic thermokarst. Roads from established mines, such as the Red Dog mine near CAKR, cross lowland areas. Heavy vehicle traffic affects not only the roadbed itself but the surrounding environment from dust, exhaust products, and the deposition of heavy metal residues.

Most of the villages within ARCN are located in lowland areas, especially near rivers, so many subsistence activities take place in the surrounding lowlands. Caribou and moose spend much of the year in lowland areas, and they are usually extensively hunted, as are waterfowl and some small game. The lowlands near villages are often subject to heavy traffic from snowmobiles and ATVs.

Freshwater Ecosystems of ARCN

The Circumpolar Hydrologic Cycle and its Implications for ARCN

The hydrologic cycle figures prominently into the dynamics of arctic ecosystems (Figure 18). In the Arctic, this tightly coupled system links land, ocean, and atmospheric components together. The contrast between summer and winter water cycles over the arctic land mass is extreme. During the summer months, the flux of mass, energy, and nutrients downstream is concentrated in a single sharp peak flow event that brings moisture to terrestrial arctic ecosystems, eventually ending up in the ocean. Surface flow, ponding, and cycles of free-thaw are the primary drivers of erosion and geomorphic change (Vörösmarty et al. 2001). In winter, ice and snow radically transform the land surface, increasing surface albedo and reducing the amount of solar energy absorbed. A unique feature of the arctic hydrologic cycle is the presence of permafrost and its associated active layer. Permafrost limits the amount of subsurface water storage, which in turn is largely controlled by surface heat flux. Although ARCN will focus its monitoring effort on the land component (Figure 10) of this tightly coupled land-ocean-atmosphere system it is necessary to point out that the surface water and energy balance is ultimately linked to the pan arctic water cycle and all of its various feedbacks.

Large Rivers of the Arctic Network

ARCN contains many large river systems, including the Noatak and Kobuk Rivers that drain west into the Kotzebue Sound and Chukchi Sea. Large rivers in ARCN usually meander through broad valleys and contain numerous side channels and sloughs (Figures 16 and 17). The structure of these large river floodplains allows for the lateral transfer of nutrients and energy throughout the valley bottom. Although few studies have been conducted on the surface-subsurface dynamics of these large arctic river systems, this exchange between surface and hyporheic waters may nonetheless be important to the functioning of these systems.

Many of the tributaries to these large rivers originate in the Brooks Range as clear-water or silt-rich glacier-fed streams. These large river systems serve as conduits for carbon, nutrient, and trace metal transport connecting the surrounding watershed with areas further downstream. In addition, many anadromous fish, riparian birds, and large mammals use these large river corridors for migration or foraging, providing yet another opportunity for exchange of energy and nutrients up or down-stream (Oswood 1997).

Historically, much of the gravel used for construction of roads and pads in Arctic Alaska has been obtained from deposits within the floodplains of large rivers. Gravel mining in floodplains of large rivers has been shown to substantially alter flow regimes of large river systems (Joyce 1980). The Alaska Department of Natural Resources (DNR) identified 2,477 potential RS 2477 rights-of-way in the state of Alaska and found

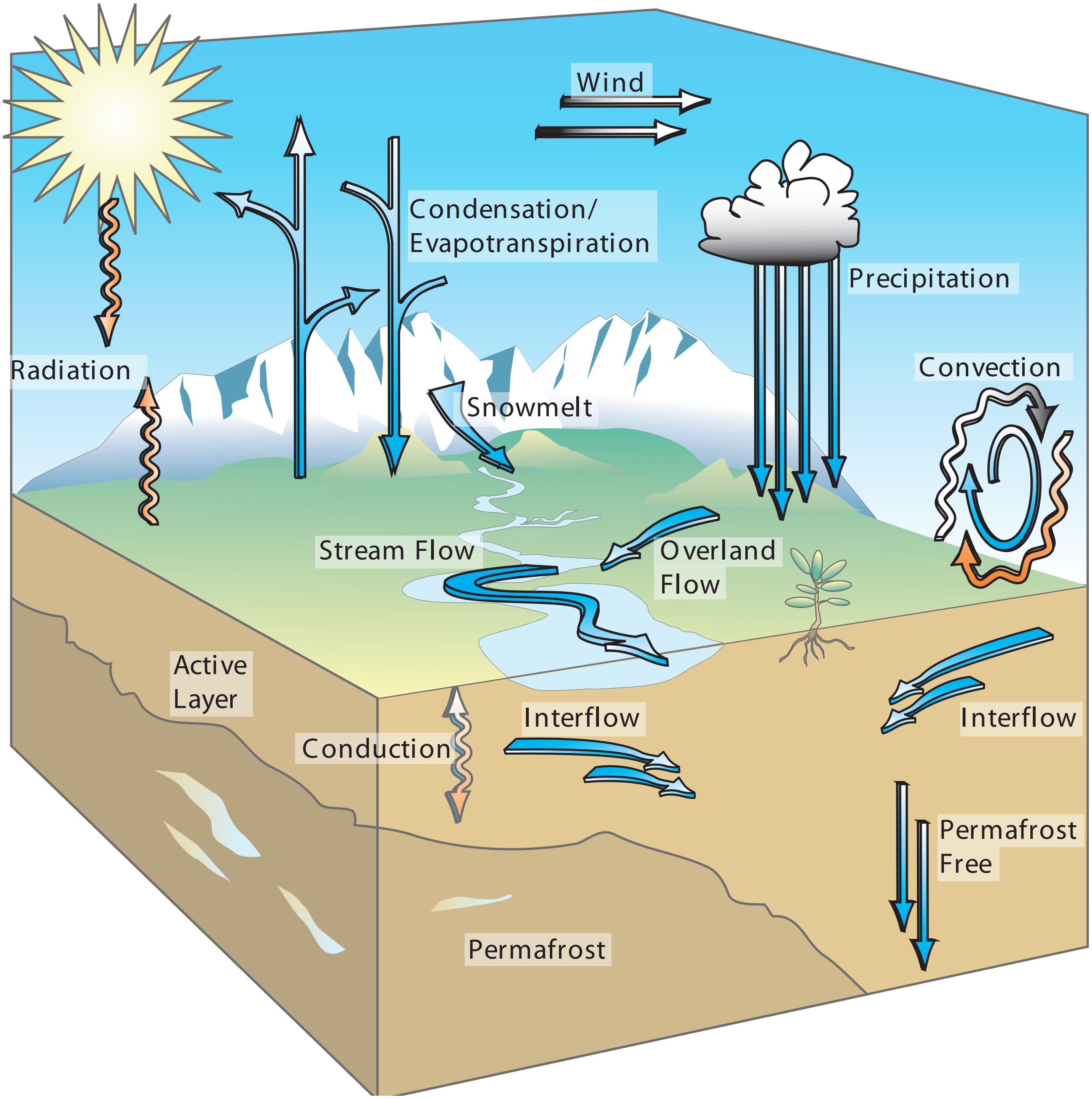


Figure 18: Conceptual model of the land surface component of the arctic hydrologic cycle and related water cycle dynamics. From the Arctic Community-wide Hydrologic Analysis and Monitoring Program (Arctic-CHAMP) Strategy Model (Vörösmarty et al. 2001).

647 that qualify. In 1998, the state legislature passed a law declaring 600 routes as RS 2477 rights-of-way by public use. In 13 national parklands in Alaska, the State of Alaska has claimed 112 potential roads totaling 2,272 miles. To date, 21 possible RS2477 Rights-of-Way have been identified by the State of Alaska in the ARCN parks (NPS, personal communication). Road development in ARCN parks could have a detrimental impact to many of the large river systems because the construction and use of gravel roads could interrupt or alter stream flow.

Headwater Streams of the Arctic Network

Three main types of headwater streams have been identified in the Alaskan arctic: mountain, tundra, and spring streams (Craig and McCart 1975).

In ARCN there are two types of mountain streams: glacier-fed mountain streams that originate as cirque glaciers high in the Brooks Range and streams fed mainly by precipitation and snowmelt. Mountain streams in ARCN drain north, south, and west out of the Brooks Range. Tundra streams are found in the foothills and coastal plain areas of ARCN, are fed mainly by snowmelt and precipitation, and are underlain by peat. Mountain and tundra streams experience extreme fluctuations in flow, with discharge highest in spring and early summer and little or no flow in winter when runoff ceases and most or all of the water column freezes. Mountain and tundra streams that experience extreme physical disturbances such as spring snowmelt and winter freezing are common in high-latitude climates. These streams tend to have low species diversity and secondary production because few aquatic species are adapted to tolerate such extreme physical changes in their environment (Figure 19).

Spring streams are fed by groundwater below or within the permafrost layer or by deep lakes and flow all year long. In many spring streams in the arctic, water temperatures exceed 5°C all year long (Craig and McCart 1975). These perennial streams are distributed throughout ARCN, contain a larger number of aquatic species, and most likely serve as refugia for taxa that are not tolerant to freezing (Figure 20).

Lakes of the Arctic Network

There are many lakes of varying sizes in ARCN (Figures 16 and 17). Many of the large deep lakes such as Chandler, Selby, Feniak, and Matcharak are well known in this region; however, thousands of shallow lakes and wetlands are distributed throughout the parks. Water from large freshwater lakes is often used to build ice roads for winter travel and oil exploration in the Alaskan Arctic. "For lakes that do not support wintering fish, there is essentially no current regulation of winter water withdrawals, and the amount estimated to be present during summer is typically set as the withdrawal limit … [which] essentially allows

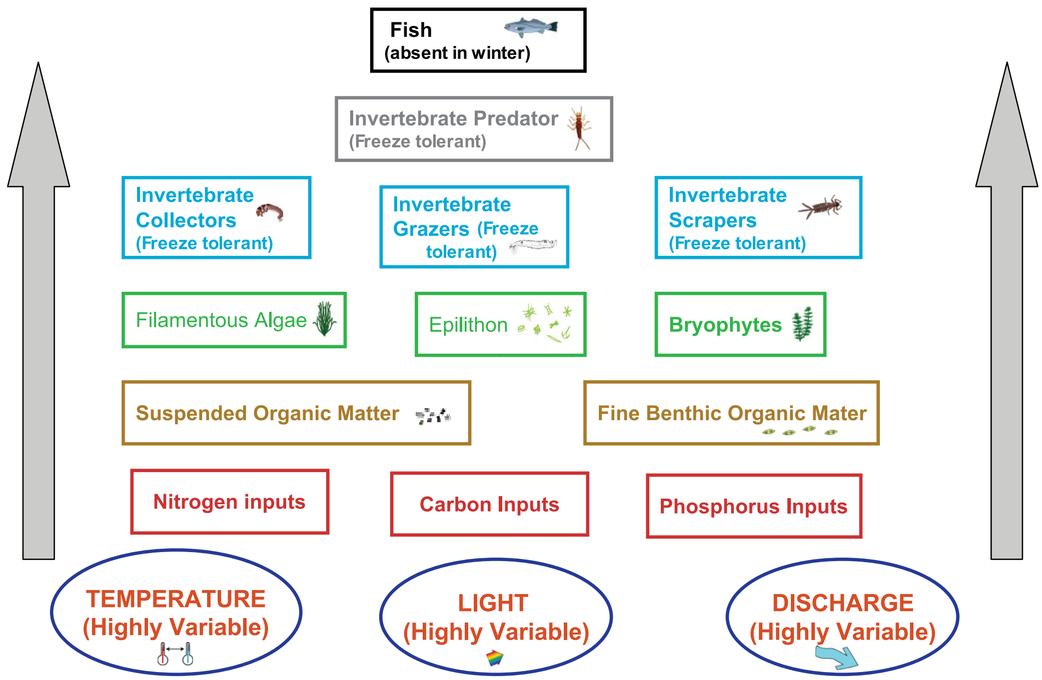


Figure 19: Simplified Mountain or Tundra Stream Foodweb. Physical disturbances and extreme fluctuations in temperature, light and discharge exert control of these foodwebs. Circles indicate physical drivers, boxes represent standing stocks and arrows represent general direction of energy flow.

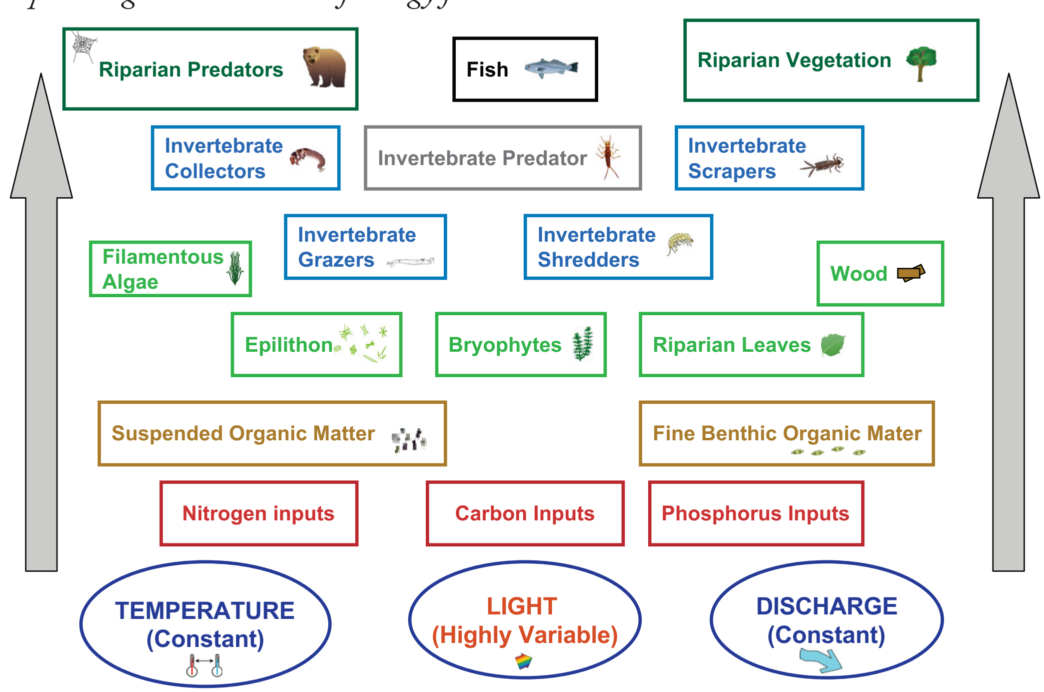


Figure 20: Simplified Arctic Spring-fed Stream Foodweb. Extreme physical disturbances are much less common in these streams than arctic mountain or tundra streams as water temperatures and discharge remain relatively constant throughout the year. Communities in these streams do however experience extreme variation in light regimes. Circles indicate physical drivers, boxes represent standing stocks and arrows represent general direction of energy flow.

withdrawal of all remaining unfrozen water in the lake at the time of withdrawal" (National Research Council 2003). Since little baseline data on the lakes of ARCN has been collected, it will be hard to monitor the actual impacts of water withdrawal on these ecosystems if additional road corridors are built within or abutting ARCN parklands.

Coastal Ecosystems of ARCN

Coastal ecosystems in ARCN are confined to CAKR, whose central feature is the extensive lagoon and barrier beach system that encompasses most of the southern portion of the monument, and BELA, much of whose northern boundary is the Chukchi Sea and Kotzebue Sound coast of the Seward Peninsula. ARCN does not include any offshore waters, but the boundary between marine and coastal ecosystems is less distinct biologically than it is geographically. Marine processes and events strongly affect the coastal environment, and vice versa. This is particularly true within ARCN, since the surrounding seas are shallow and the sea bed was emergent as recently as the terminal Pleistocene, roughly 10,000 years ago. Rising sea levels during the Holocene have been instrumental in shaping the landscape and ecosystems of the coastal regions of ARCN, and this continues in the present.

Polar marine ecosystems are coming to be recognized as being extraordinarily sensitive to environmental change. Reductions in sea ice cover can have profound effects on ice-dependent species such as polar bears and ringed seals. The long food chains of the seas encourage the biological concentration of various pollutants at the higher trophic levels. Heavy exploitation of marine resources, especially ground fish, seems to have the potential to disrupt long-established ecosystems to the point that they change their essential nature. These changes may be, for all practical purposes, permanent. Fundamental changes seem to be occurring in the nature of the Bering Sea, within a few hundred kilometers of ARCN. The marine environment immediately adjacent to ARCN is thus of great interest to monitoring programs within the study area.

Coastal ecosystems within ARCN can, somewhat arbitrarily, be divided into four categories, which we have shown graphically as Figures 20, 21, 22, and 24. Rocky coastlines (Figure 20) are relatively rare within ARCN. More extensive are shorelines where the sea borders low-lying tundra developed on unconsolidated sediments (Figure 21). Lagoon and barrier beach systems are extensive and important in both CAKR and BELA (Figure 22). Delta ecosystems are also an important habitat in coastal areas of ARCN (Figure 24).

Rocky Shores

Rocky shores occur mainly along the Kotzebue Sound coast of BELA. These shores are generally low-lying and are formed from lava flows of various ages (Figure 21). Above the inshore limit of storm beaches and

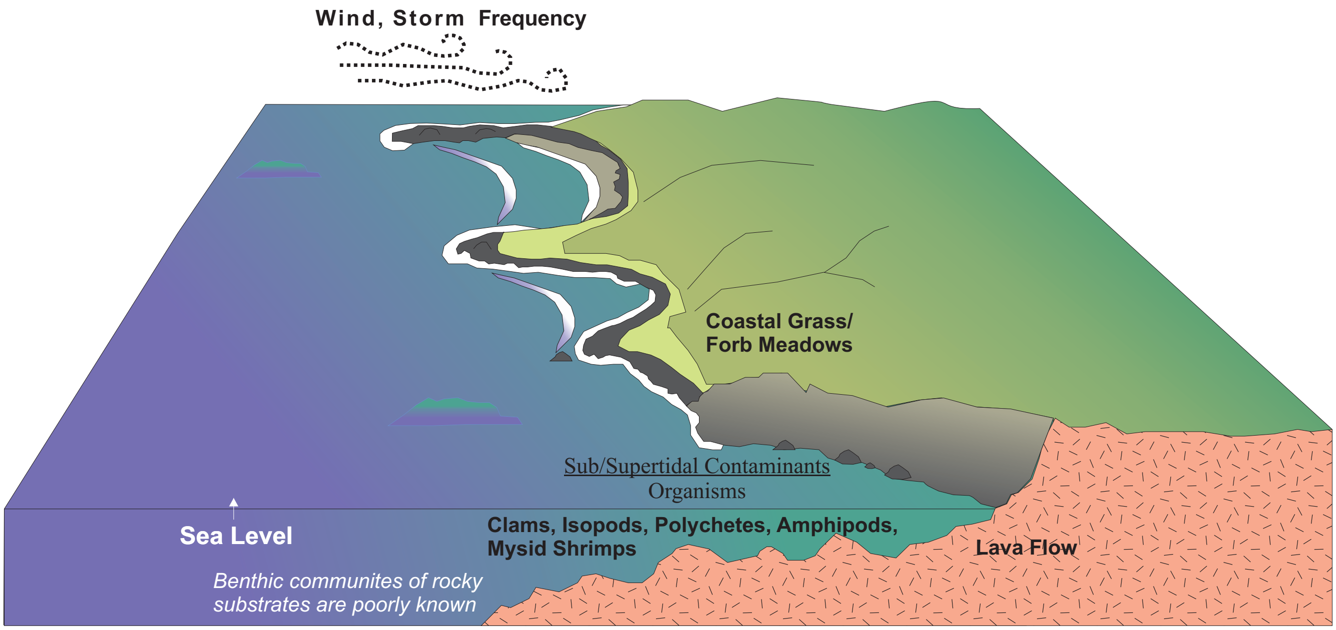


Figure 21. Rocky cliff shorelines of ARCN.

beach deposits, the vegetation is often affected by salt carried onshore by wind; a few species of lichens and vascular plants are encouraged by or confined to saline situations. Near the eastern boundary there are some sea cliffs that support small colonies of cliff-nesting seabirds. With the exception of seabirds, few if any species of vertebrates are characteristically found primarily along rocky shores. Benthic communities of rocky substrates are poorly known in this area and further study is needed.

Exposed Tundra Coastlines

In areas where lagoon and barrier beach systems have not developed, the coastal environment is often confined to a relatively narrow strip of beach (Figure 22). In some cases, the sea may even undercut deep deposits of ice-rich unconsolidated sediments, so that the interface between the sea and the terrestrial environment is a narrow zone of collapsing bluffs. In situations where the bluffs are low, no more than a meter or two high, sea ice may actually override the tundra during winter storms, leaving sea ice and detritus lying on the land surface.

Within ARCN, tundra coastlines are generally receding. The main phenomena associated with the incursion of the sea is the loss of terrestrial environment and the dispersal into the sea of sediments and nutrients that have been contained in the largely frozen terrestrial situations. The spread of saline conditions inland from salt spray and encroaching sea ice may also be important.

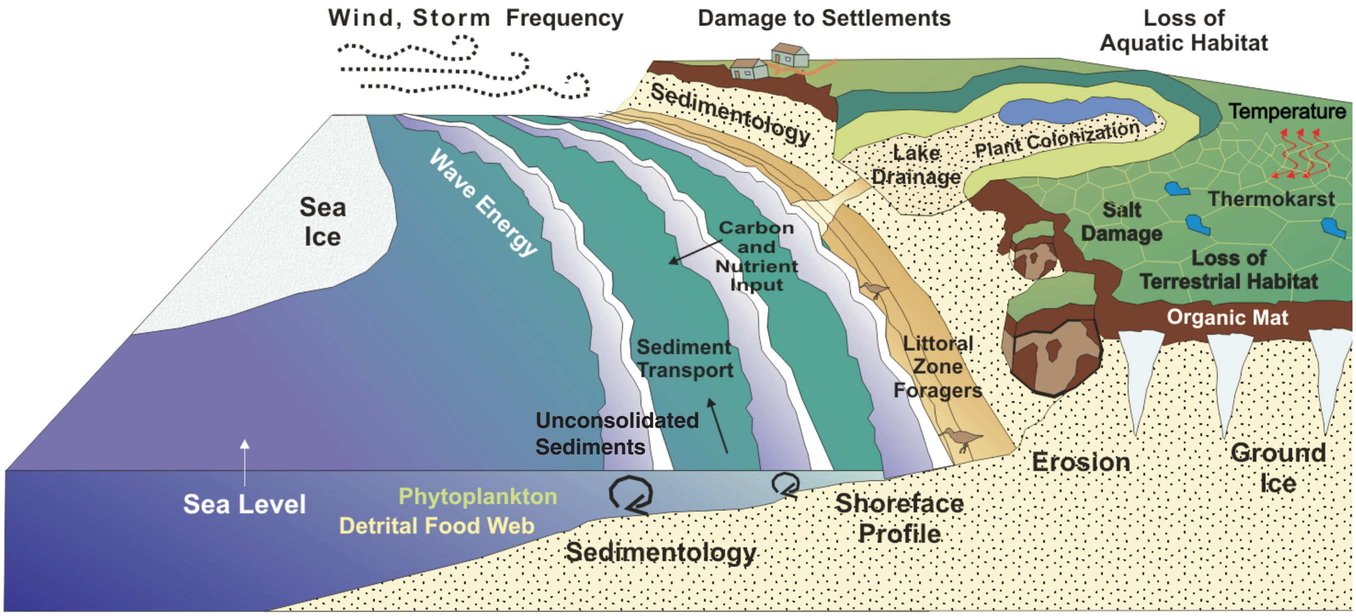


Figure 22. Exposed tundra coastline

Another feature associated with encroaching seas is the drainage of coastal lakes and thaw ponds. Even shallow tundra ponds have generally existed for long periods of time—hundreds or thousands of years, and the presence of surface water that does not freeze to the bottom in winter allows the degradation of permafrost under the lake bed. When the encroaching seashore intersects the unfrozen and unconsolidated material of the lake bed and shore, a drainage channel may appear suddenly and the lake may drain entirely away over a short time. This provides a new, often well-drained and enriched soil surface for colonization by plants. Also, much of the surface sediment and nutrients of the lake bed may be discharged into the nearby marine ecosystem. Ultimately, a new permafrost regime will be initiated in the old lake bed, which is no longer insulated from the extreme cold of winter.

Since the actual area included in tundra coastlines is small and generally unstable, there are few vertebrate species specifically associated with this habitat type. It is often used by migrating waterfowl and shorebirds, and the often large quantity of detritus and carcasses of marine mammals and birds often attracts scavengers such as arctic foxes (*Alopex lagopus*) and ravens (*Corvus corax*).

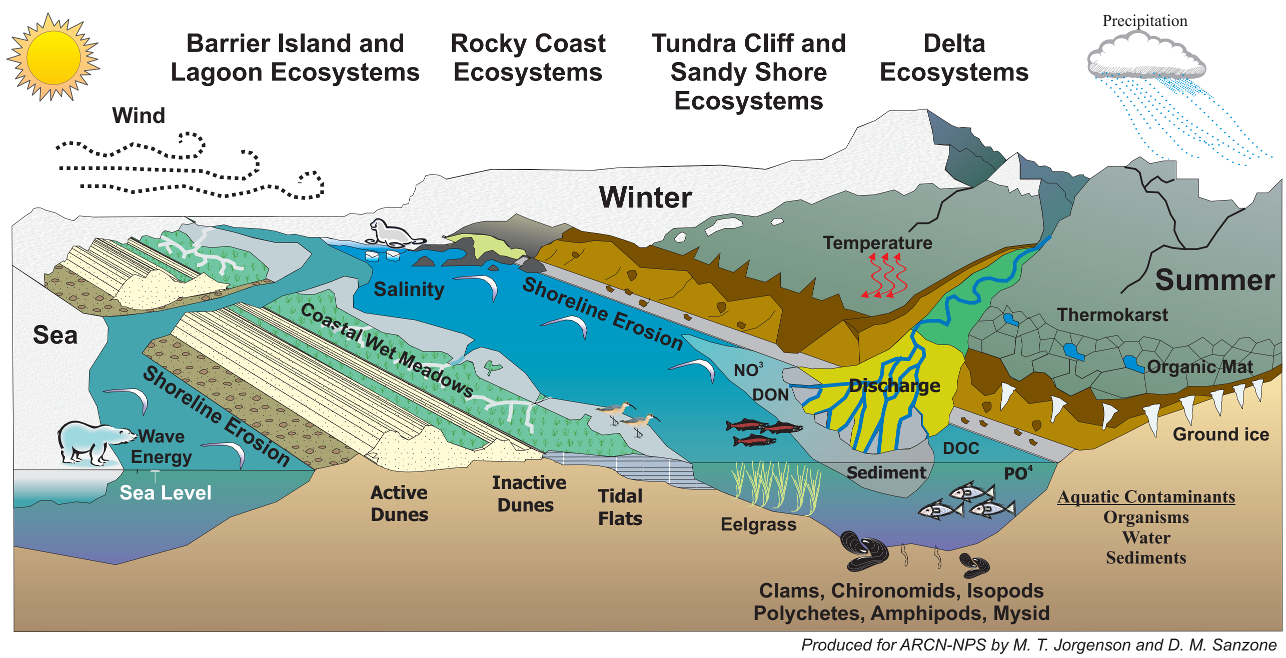
Tundra shorelines are subject to a good deal of anthropogenic disturbance, mainly because they are heavily used corridors for travel during the summer by ATVs. The narrowness of the beaches and the dry edges of the tundra bluffs confines vehicle travel to this narrow strip, and heavy erosion may result. Although there is also heavy winter travel by snowmobile, damage is less when the ground is frozen and snow-covered.

Lagoon and Barrier Beach Systems

Lagoon and barrier beach complexes (Figure 23) encompass most of the northern (Chukchi Sea) coast of BELA and are extensively developed along the coast of CAKR, especially in the southern portion. Cape Krusenstern itself is formed by an ancient and extensive barrier beach formation that is of enormous archaeological significance; this was central to the selection of CAKR as a national monument.

In contrast to tundra coastlines, barrier beaches are often aggrading, and many have been doing so for several thousand years, since the time when sea level reached nearly its present elevation. At Cape Krusenstern, over 150 separate beach ridges have been identified. The oldest to youngest are found in sequence from farthest inland to the presently active coast. This provides a time sequence similar to that more typically found in vertically stratified sites.

Barrier beach complexes may be as much as one kilometer or more wide; the ridges are separated by shallow backshore swales that parallel the ridges. The ridgetops generally support thin stands of vegetation, with lyme grass (*Elymus arenarius*) the dominant species. In areas of dunes, lyme grass stands are especially well developed. The swales are variable; some are water filled during much or all of the year, other are mostly dry.



Regional and Anthropogenic Stressors

ATMOSPHERIC	OCEANOGRAPHIC	GEOMORPHIC	HYDROLOGIC	BIOTIC	ANTHROPOGENIC
↑ Air Temperature	↑ Sea Level	↑ Shoreline Erosion	Δ Precipitation	Vegetation, Invertebrates	↑ Airborne Pollution
↑ Storminess	↑ Storm surges	Δ Barrier Island Migration	Δ Evaporation	Fish, Birds, Mammals	Δ Mining Activity
↓ Snow Cover	↓ Sea Ice	Δ Marine Sedi. Transport	Δ River Discharge	Δ Population Abundance	Δ Oil and Gas Activity
Δ Precipitation	↑ Fetch Length	Δ Land Sediment Deposit.	Δ Lake Extent	Δ Range Shifts	Δ Subsistence Harvest
↑ Nitrogen Input	↑ Wave Energy	Δ Dune Formation/Scouring	Δ Nutrient Load	Δ Community Structure	Δ Recreation
↑ Contaminants		↑ Thermokarst	Δ Sediment Load	Δ Foodweb	Δ Transportation
↓ Albedo		↑ Active Layer		Δ Exotic Species	Δ Noise
					Δ Land Use Regs.
					Δ Villages, Inholdings
					Δ Pollution

Figure 23: Lagoon and barrier beach ecosystem

They provide a wide variety of habitats and are especially important as breeding grounds for shorebirds and terns. They may also support populations of various microtine rodents; these are preyed upon by foxes and predatory birds such as short-eared owls and northern harriers (*Circus cyaneus*). Some of the deeper, more stable hollows contain dense willow thickets.

Although many barrier beaches have been stable for thousands of years, others are subject to very active shoreline erosion as well as aggradation. Wave action may actually breach the barriers, endangering coastal settlements and archaeological sites and radically changing the nature of associated lagoons.

Inland from the backshore may lie an extensive lagoon system. These lagoons are also highly variable, especially in terms of salinity. Some are actually open to the sea by way of passages through the barrier beach complex, and the waters are highly saline, modified only by the inflow of streams (Figure 24a). Other lagoons are generally only slightly brackish, their salinity derived from exceptional tides sending sea water up their discharge channels or, if the barrier beach is narrow, waves washing over it (24b). Lesser amounts of salt arrive from sea winds, and probably in some cases by percolation through the coarse sediments of the barrier beaches.

The shores and shallow portions of lagoons support extensive wet meadows; these are often punctuated by small ponds. This is an important habitat for many species of shorebirds and waterfowl. Certain species (e.g., red phalarope, *Phalaropus fulicaria*) are mostly confined as breeding species to coastal ponds. Waterfowl often congregate there in great numbers during molt and migration.

The inland shores of lagoons are also quite variable. In some cases they merge imperceptibly into adjacent wet coastal tundra. In others, they may border an eroding shoreline comparable to coastal tundra shorelines; these are usually less active, since there is less wave and tide action. Lagoons are also fed by streams originating inland; these may carry sediments and nutrients into the lagoon environment. The streams often form small estuaries, with extensive marshes and overflow channels.

Lagoons are relatively little used by large mammals. An exception is large, open lagoons, which may be important hauling areas for seals and may be visited by beluga whales. After winter freeze-up, coastal marshes may supply some fodder for herbivores. Caribou, moose, and muskox may visit barrier beaches at various times of the year. On-shore breezes may make them particularly attractive to caribou, because the wind keeps insects away.

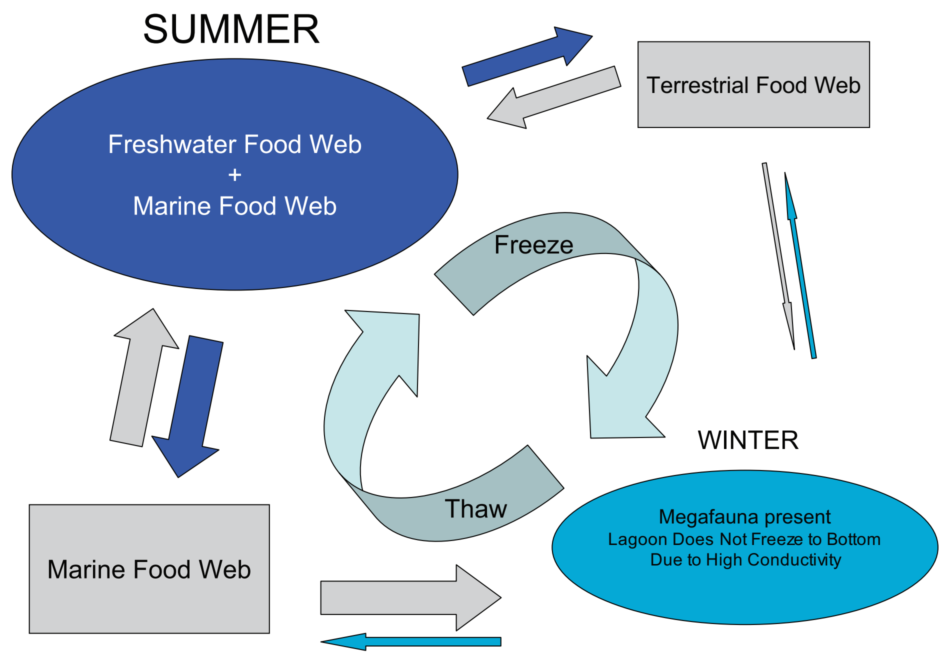


Figure 24a. Open Lagoon Systems of ARCN

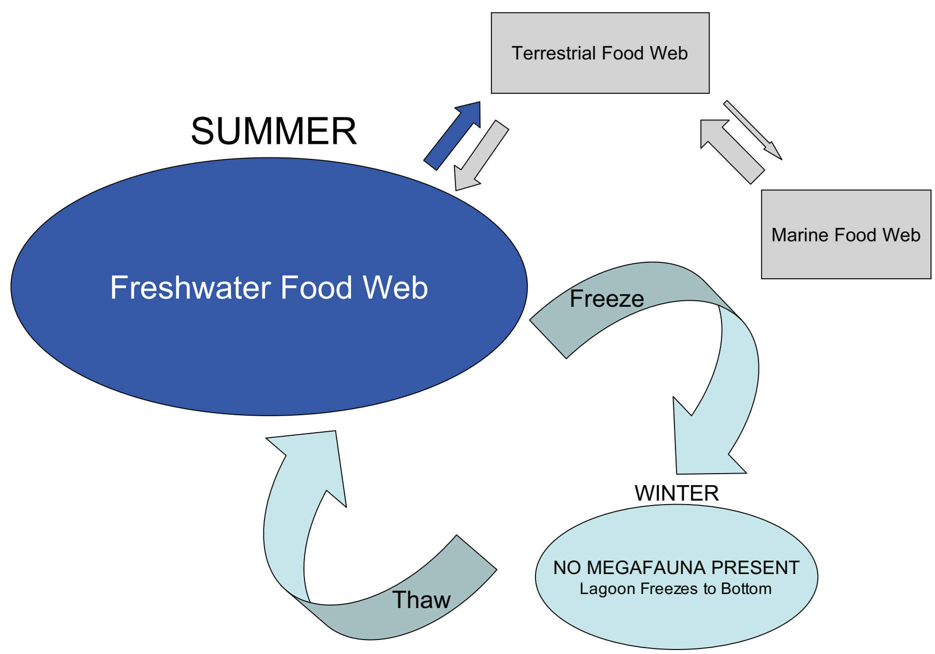


Figure 24b. Closed lagoon ecosystems of ARCN

Barrier beaches are subject to the same pressures from ATVs as tundra coastlines. The traveled corridors may be a bit wider and damage less obvious. During warmer seasons, when the ice is off the lagoons, they may receive some hunting and fishing pressure. Lagoons are obviously extremely sensitive to point source pollution from their shores or feeder streams, since they are largely closed systems.

Delta Ecosystems

The distinction between estuaries and lagoons is not always clear. Most streams that pass through lowland areas before entering the ocean are associated with complexes of beaches and other sediment deposits that form at least rudimentary lagoon systems. The features and processes that generally distinguish delta systems are significant river discharge and sediment load, strong effects of tidal influx, major rapid changes in water level and salinity, strong effects of ice from rivers and/or the sea, often extensive mud flats, and marshes with highly salt tolerant plant species (Figure 25). All of these vary greatly within the system, depending on factors such as microtopography and distance from the river shore and sea coast. Overall, estuarine systems are more dynamic, higher energy, and generally richer in nutrients and species of plants and animals than other coastal environments.

Estuaries are generally associated with sizeable streams, and these carry sediments from far inland. The higher energy streams may provide coarser sediments of sands and silts. Siltation may encourage mudflats in low-lying areas that might otherwise be heavily vegetated marshes. The high sediment load also may result in relatively high nutrient levels in the shallow waters and marshes. Association with larger streams also encourages the presence of anadromous fish. The estuaries and lower reaches of the feeder streams may provide important habitat for young salmonids.

As in the case of lagoons, estuaries are especially heavily frequented by birds, especially shorebirds and waterfowl. Estuarine shores are particularly well known as resting places for migrating shorebirds; their productivity and diversity provides a wide variety of invertebrates and small fish, high-energy food for birds that travel long distances.

Estuarine ecosystems are often heavily used by subsistence hunters and both subsistence and commercial fishermen. Small runs of salmon, espe-

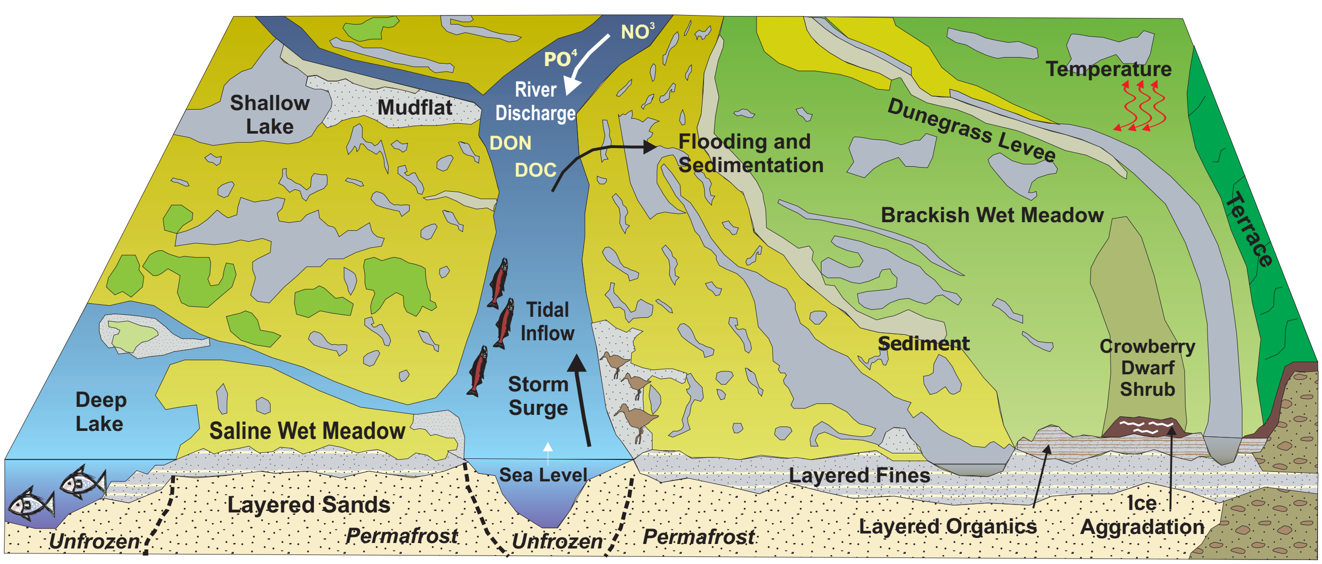


Figure 25. Delta ecosystems of ARCN

cially pink and chum salmon, occur in several of the river systems within coastal ARCN. Waterfowl are heavily used. Terrestrial vertebrates are generally uncommon in estuarine environments, especially in summer when footing is treacherous and insect swarms are heavy. Estuaries are affected by a variety of pollutants, both chemical and physical. Upstream activities may increase silt loads of streams, spills from boats and nearby hunting and fishing camps may be common, and some sea-borne organic pollutants may be locally significant. Because the most significant estuarine ecosystems occur within a meter or so above or below mean high tide level, estuarine ecosystems are strongly affected by minor changes in sea level.

Special Areas of Management Concern for ARCN

Conceptual Framework for Considering Climatic Change

It is generally accepted that global warming is occurring and that it is especially evident in high-latitude regions. While it is generally assumed that warming is a process that will continue into the foreseeable future, it is not inconceivable that cooling trends could develop. This is especially true over the very long (centuries or millennia) term, when orbital forcing or other factors could theoretically terminate the current interglacial. In the following model, we consider the potential effects of climatic cooling as well as warming. In the case of either warming or cooling trends in arctic environments, there are feedback mechanisms that suggest that some results of either process are counterintuitive. Scenarios based on regional warming or cooling trends that consider only annual means do not take into account changes in the seasonality that may occur. Increased seasonality, often associated with increased continentality, means, under a warming trend, warmer summers; decreased seasonality means warmer winters. Thus, a warming trend that involves increased winter temperature may increase precipitation, resulting in greater snowfall, delayed onset of the growing season, and quite possibly increased cloud cover during summer. A consequence of this could actually be lowered air and soil temperatures at ground level. The result of a warming trend might then appear at the vegetation level as stress on "warm climate" plants: those that require certain levels or duration of warmth during the growing season. Over the long term, this could, theoretically, result in the retraction or fragmentation of the ranges of "low arctic" species in areas such as the North Slope of the Brooks Range. This concept leads directly to concerns of range extension and retraction, such as the location of the treeline (see below).

The example developed above is obviously simplified and isolated from many related factors. It also says little about the scale of time and space over which effects might be visible. For example, a long-term warming trend would probably result in a thinning of the sea ice cover, so that open water near the north and west coast of Alaska would extend farther from the shore and remain open for more months of the year. This might set up a feedback loop in which additional warming was encouraged by the lowered albedo of the open sea as opposed to pack ice. On the other hand, increased open water could increase precipitation and cloudiness over the land, tending to reverse the warming trend. But this in turn would depend at least partially on wind and other weather patterns; these are notoriously difficult to predict, and there is usually wide variation between results when only slight modifications are made in the parameters that are fed into climatic models.

The diagram presented here attempts to show graphically how a general warming or cooling trend might be expected to affect the nature of the physical environment at high latitudes (Figure 26). It includes examples of some of the feedback loops that could tend to drive the system toward, or away from, stability.

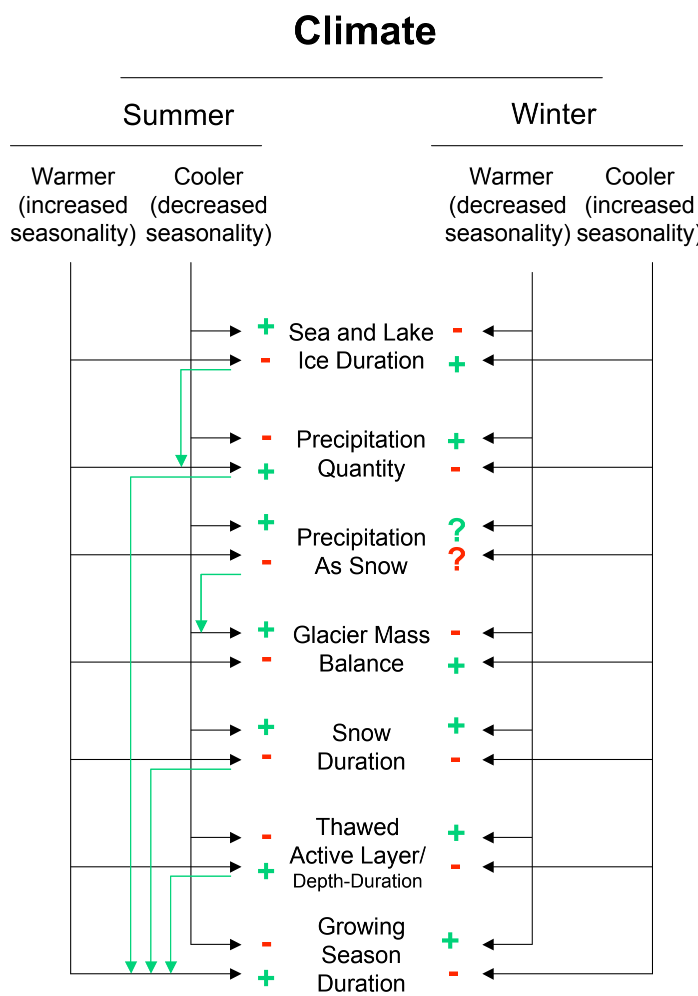


Figure 26: Simplified model of climate change in arctic ecosystems.

A Conceptual Framework for Considering Changing Plant Distribution Patterns in the Arctic Network: Northward Movement of Treeline

Long-term changes in climate are associated with changes in the distributions of various organisms (Figure 27). In the North, the most conspicuous and well-studied expression of this is the location of the treeline, often defined as the poleward or seaward limit of coniferous forest. The correlation of the location of treeline with summer temperature is well known (Young 1989); and it is generally accepted that the location of the northernmost forests closely approximates the location of the 10° C isotherm for the warmest month of the year, July in most parts of the North. However, this is only a rough correlation. The array of physiological processes that facilitate or limit the northward spread of certain tree species must take place at a microclimatic level, there may be more than a single set of limiting factors, and different sets of factors may be operating under different climatic conditions and in different geographic areas.

For example, the limiting factor in some situations might be the production of viable seed, which would require certain conditions of intensity and duration of warmth in the upper portions of mature trees during the growing season. On the other hand, germination and establishment of seeds might be the weak link in the chain, in which case temperatures at the soil surface would probably be critical. In this case, factors such as depth and duration of snow cover and/or shade from nearby mature trees might become dominant in determining success of reproduction

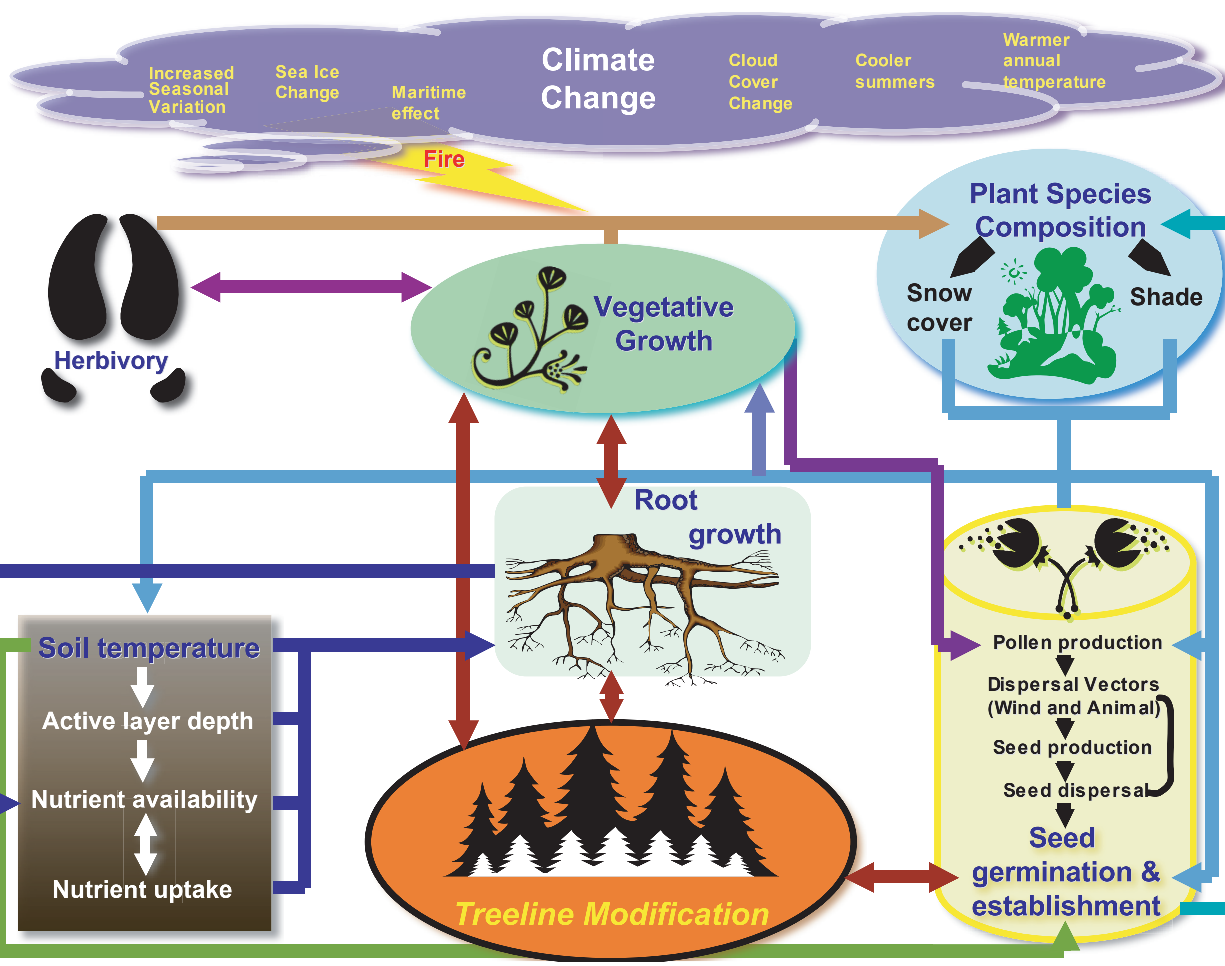


Figure 27: Biomechanics and feedback loops of treeline modification in relation to climate change.

and, over time, the advance or retreat of the forest. An additional complexity, of course, is the consideration that necessary conditions need to be met only often enough to allow successful reproduction occasionally during the long life span of plants such as conifer trees. Thus, a cooling but unstable climatic regime with an occasional unusually warm summer could conceivably facilitate the spread of trees more effectively than a slightly warmer but more stable climate.

Even this brief consideration of one type of distribution pattern points up the complexity of factors that are implicated in controlling the advance or retraction of the ranges of plants and animals. It will be noted that we have not mentioned the role of dispersal mechanisms and their effectiveness. These would presumably have little relevance with respect to current treeline trees, but the spread of some other organisms could be quite dependent on effective dispersal mechanisms.

Finally, we might note that the presence or absence of conspicuous organisms such as forest trees is easily established, and the changes in their distributions can be monitored by such means as aerial photography. Even ancient ranges can be provisionally plotted on the basis of fossil evidence. This becomes only somewhat less true in the case of species such as shrub birch (*Betula glandulosa* and related forms) or the various willows that comprise the overstory of the riparian shrub communities. In the case of less conspicuous species, such as tussock-forming cottongrass (*Eriophorum vaginatum*), only careful, on-the-ground studies may be able to show its presence or absence or its advance or retreat.

Equally important, changes in the distribution of a species such as the above could occur either by migration along a broad front or by the expansion of small, isolated, perhaps relict colonies outside the "normal" range of the species. Under the latter situation, range extensions could be expected to occur much more rapidly in response to changing climate or other environmental changes.

In spite of the complexity noted above, alterations in the distribution of various species and communities can be expected to lead to some of the most powerful concepts and tools with which to monitor the trajectory of overall environmental changes and of the "health" of the environment in general. We have concentrated here, and in the accompanying diagram, on plant species and some of the factors and interactions that can be involved in changes in distribution. In some cases, the migration and range extension of certain vertebrates and invertebrates would be dependent on the spread or retreat of vegetation types. This is probably at least partially the case, for example, in the spread of moose into arctic Alaska over the past couple of centuries. In other cases, especially in highly mobile species such as some migratory birds, the correlation between range changes and climatic or other environmental change is difficult to address successfully. Studies addressing these issues will probably be important in any long-term monitoring program in our study area.

Conceptual Framework for Thinking About Biodiversity in the Arctic Network

The National Park System plays a critical role in the preservation of biodiversity. ARCN parklands contain many of the Arctic's unique ecosystems intact, making the parks critically important to species survival. Biodiversity in the Arctic must be considered from a different perspective than in temperate and tropical regions (Figure 28). For most groups of organisms, the number of species found in a given area is only a fraction of the number that would occur in a comparable space in lower latitudes. For example, the boreal forest of northwestern Alaska may contain no more than a half-dozen tree species. Of these, one, white spruce (*Picea glauca*), may outnumber all other tree species by a wide margin over enormous areas. Large herbivores may be only two to four species (caribou and moose, with muskox and Dall's sheep in some locations).

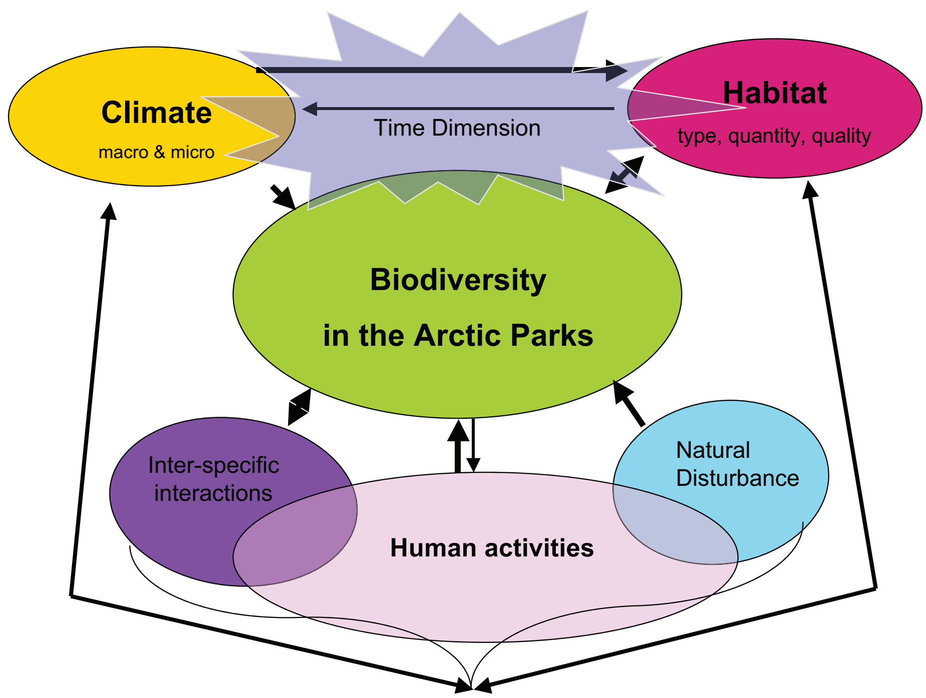


Figure 28: Biodiversity in the arctic parklands.

Many of the species that do occur in the Arctic are of extraordinarily broad distribution. White spruce dominates the boreal forest from western Alaska to eastern Newfoundland, while both caribou and moose, as well as wolves and brown bear, have completely circumpolar ranges. This is also true for many smaller vertebrates, as well as many of the important species of higher plants, mosses, and lichens.

This would suggest that biodiversity in high northern latitudes is low, and that many of the species are so widespread as to be buffered from the effects of local events and processes that could negatively affect their populations. In fact, the situation is much more complex. While the "fragility" of the arctic environment has probably been overemphasized, there are a number of aspects of arctic ecosystems, at all scales, that lead to a high level of vulnerability.

Arctic ecosystems are unusual in that they often are reconstituted in a major way over relatively short periods of time. For example, an area of tundra that one year has a high population of microtine rodents, which are preyed upon by a array of predators such as snowy owls, jaegers, and arctic foxes, may, only a year later, be almost devoid of small mammals. This, of course, disrupts the entire predator-prey relationship; the predators may migrate elsewhere or cease to breed for that year. Similarly, the nutrient/fertility relationship between small herbivores and plants may be radically altered from year to year. Similar situations may occur in the case of large herbivores such as caribou, whose numbers may fluctuate wildly over periods of only a few years. At various points in these cycles, especially at the time they "crash," relatively minor changes in other aspects of the environment may make the difference between a fairly rapid recovery and an extended decline.

In many cases, the causes of population declines are poorly understood. The most spectacular examples are found in marine mammals, such as in the precipitous loss of a major proportion of the populations of sea otters, fur seals, and Steller's sea lions in the southern Bering Sea. Something similar has happened to several species of waterfowl, such as spectacled eider and emperor goose.

There are, of course, major changes in the arctic ecosystem from season to season. During the winter, many areas may have a resident bird population of less than a half-dozen species (e.g., rock and willow ptarmigan, gyrfalcon, and raven) while in the summer the number might swell to 50 or more species breeding within an area of a few square kilometers. Both the array of species and the numbers of individuals may vary significantly from year to year, as may breeding success.

It is important to keep in mind that the arctic ecosystem is very young in terms of geologic time. Most of the North American Arctic was under ice within the last 8,000 to 12,000 years. In glaciated areas, the entire biota has had to be rebuilt by migrants from afar since the end of the last Ice Age. In many cases, it appears that the process is still incomplete. Grizzly bears, for example, have yet to colonize the eastern Canadian Arctic successfully. The biodiversity of large regions of the North American Arctic have yet to stabilize after the retreat of the ice.

It is interesting that ARCN lies within a zone of contact between the recently deglaciated North American Arctic and the much less heavily glaciated, and thus in some senses much more ancient, Asian Arctic. Much of BELA, CAKR, NOAT, and KOVA were not glaciated in the later Pleistocene and were essentially a part of the Asian Arctic, connected by the dry land of the Bering Land Bridge. Thus, these areas both share some of the ancient aspects of Arctic Asia and have also served as migratory pathways for the recolonization of the glaciated lands to the east. As a result of this unusual history, the lands within ARCN often have a higher level of diversity of such organisms as vascular plants, small mammals, and insects, compared to other parts of the North American Arctic. Not only are there a certain number of endemic species, but there are often isolated populations of rare species and unusual communities of unusual species and combinations of species. In addition, Asian species, at least of birds, seem to still be actively colonizing the western Alaskan Arctic. Examples are white wagtail and arctic warbler. Some sea birds, such as black guillemot, are also actively changing their ranges.

While biodiversity issues are complex throughout the entire Arctic, it is safe to say that this is especially true within ARCN. There are more species of many groups of organisms, their population and community structure is more variable, and changes appear to be more rapid than in many other parts of the North. It is important to recognize that many of these local peculiarities are poorly understood and poorly documented at this time. There is no question that many additional examples will come to light as more research is done within ARCN. We are still in the early stages of gathering baseline data on the components and nature of the ecosystems represented in ARCN, and this basic enumeration of the biodiversity of the region will continue far into the future.

Changes in Biogeochemistry in the Arctic Network

Ecosystem-level response to human-induced disturbance in the Arctic can be tracked by monitoring shifts in net primary productivity (NPP) and cycling of carbon (C), nitrogen (N), and phosphorus (P). Focusing on the biogeochemistry of the boreal and tundra regions will elucidate the underlying links and feedbacks between biogeochemical cycling, changes in species composition, and landscape-level consequences of these changes (Figure 29).

The tundra and boreal biomes represented in the Arctic Network parks contain large reservoirs of C, N, and P. High-latitude terrestrial soils contain from 20 to 45 percent of the global pool of soil organic C and only a small percentage of total soil N and P contained therein is available for plant uptake. These reservoirs have accumulated as a result of slow rates of nutrient cycling in large areas of these biomes, which are dominated by continuous permafrost. The "active" soil layer of these permafrost-dominated ecosystems have characteristically low temperatures and high moisture content. This leads to slow or no decomposition of soil organic matter (SOM) that lies largely below annual thaw depth. Therefore most of the nutrients in these reservoirs are not available for plant uptake. Resultant nitrogen and phosphorus limitation of plant growth in arctic and subarctic regions has been well documented.

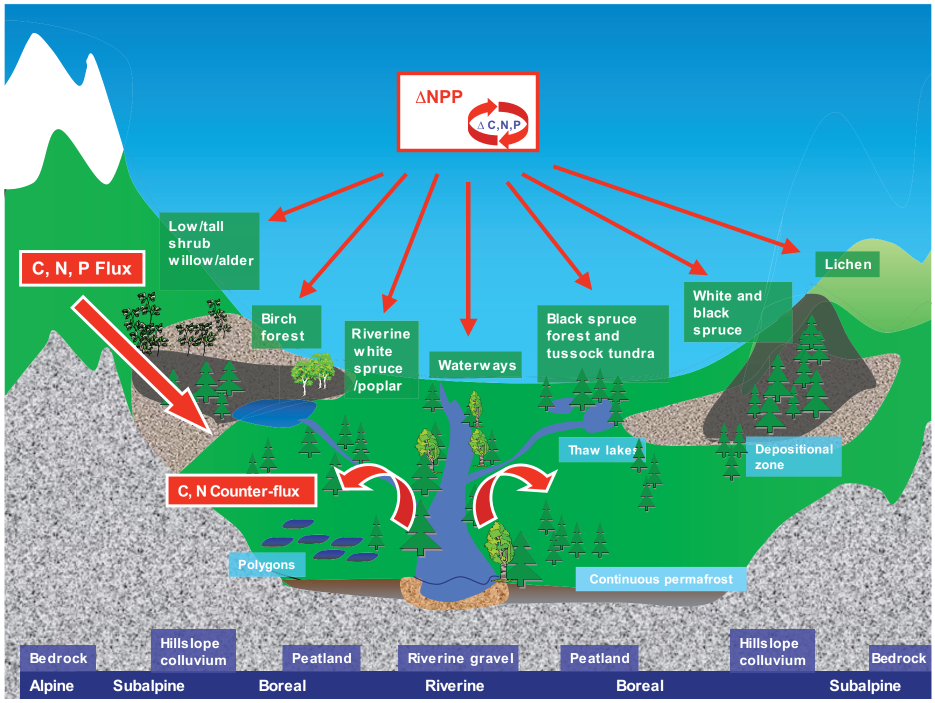


Figure 29. Ecosystem-level response to anthropogenic disturbance can be tracked by monitoring shifts in net primary productivity (NPP), cycling of carbon (C), or flux of nitrogen (N) and phosphorus (P).

One of the main ecosystem drivers in the arctic is climate. Much evidence shows that temperatures are steadily increasing in arctic regions. Ambient temperatures in northwest Alaska have increased since 1950 (Stottlemyer et al. 2001). This may be associated with increased soil active layer depth and permafrost depth which may in turn be linked to altered soil moisture, soil temperature, SOM decomposition and soil respiration rates. Expected higher soil temperatures may alter rates of N mineralization, dissolved organic carbon (DOC), and dissolved organic nitrogen (DON) release and subsequent transport to aquatic systems. This additional input of carbon and nitrogen to freshwater and coastal ecosystems could have an effect on the overall nutrient balance of aquatic ecosystems in ARCN. Tracking the large-scale effects of changing climate on the boreal and tundra biomes will require in-depth investigation of current and future relationships between soil conditions and SOM as well as other element cycles, specifically N.

Physical changes in the landscape caused by increased temperatures could also have ecosystem-level consequences in ARCN parks. For example, increased temperatures would likely cause increased development of thermokarsts, depressions caused by selective thawing of ground ice or permafrost. The additional input of C, N, P and trace elements to aquatic systems from thermokarst areas could have far-reaching effects on the biological community. Understanding the relationship between large-scale physical changes to arctic park ecosystems and the coupled chemical and biological processes will be crucial to monitoring ecosystem-level change in ARCN.

Increased ambient temperatures may also directly stimulate primary production to some extent but it appears to be more likely that increased growth is primarily a factor of higher rates of N mineralization and therefore availability. Changing climate and associated factors have already resulted in increased tree growth and associated advancement of treeline into the tundra biome (Figure 27). Ecosystem-scale monitoring may be necessary to elucidate such patterns.

Potential Pathways and Ecosystem-level Consequences of Air Pollutants in Arctic Parklands

Air toxins, such as mercury and persistent organic pollutants, are produced by a variety of sources. These can be point sources, for example from a power plant, metal smelter, or pool of spilled oil, or much more diffuse nonpoint sources, for example vehicles whose emissions vary in location depending on where the car is being operated. These sources may be close to (e.g., Red Dog Mine), or far away from (e.g., Russia and China) ARCN parklands. The emissions from these sources can be emitted directly into the atmosphere (for example out of a power plant stack), or can be introduced into the atmosphere through the volatilization of a compound released into the soil or water (such as the volatilization of light hydrocarbons from an oil spill). Once the emissions have been produced, they can be transported to the parks through global and local circulation patterns. Two good examples of this are the transport of Russian pollution into the arctic parks in winter (Arctic Haze) and the transport of Chinese dust and pollution into the Arctic in spring.

Air toxins can influence the ARCN parklands through a variety of mechanisms (Figure 30). The toxins can directly impact geophysical processes or can enter the ecosystem through deposition and then impact biological/biochemical processes. For example, air toxins can change the observed atmospheric geophysical properties by changing the albedo (the reflectivity of the earth's surface and atmosphere to solar radiation) over the parks, changing the frequency and types of clouds occurring in the region, and changing the frequency of precipitation. These effects change the amount of solar radiation and precipitation reaching the surface. This could lead to an increased growing period (if the cloud amount decreases and more sun reaches the surface) or a decreased growing period (if the precipitation pattern changes to more precipitation during winter and higher snow depths). In addition to these direct geophysical effects, the transported toxins can also be deposited to the parks' ecosystems through dry deposition (settling) or wet deposition (precipitation). As the toxins accumulate in the ecosystems, they can cause a variety of biological responses. Among these responses are the alteration of physiological integrity, reproductive viability, resistance to disease and behavior. All of these effects can make plants and animals more susceptible to changes in their ecosystems and potentially less viable. The toxins can also have biogeochemical effects, altering nutrient cycles, energy and carbon cycles, and hydrologic cycles. These effects can be cumulative, especially if multiple stressing mechanisms are involved. The overall effects of multiple ecosystem stressors could include changes in species composition and population size (e.g., more moose and fewer caribou), decrease in ecosystem integrity (e.g., making plants less able to adapt to a changing climate), replacement of sensitive with more tolerant species (such as a replacement of tundra with shrubs), or the extirpation of species or communities (e.g., alpine wetland communities).

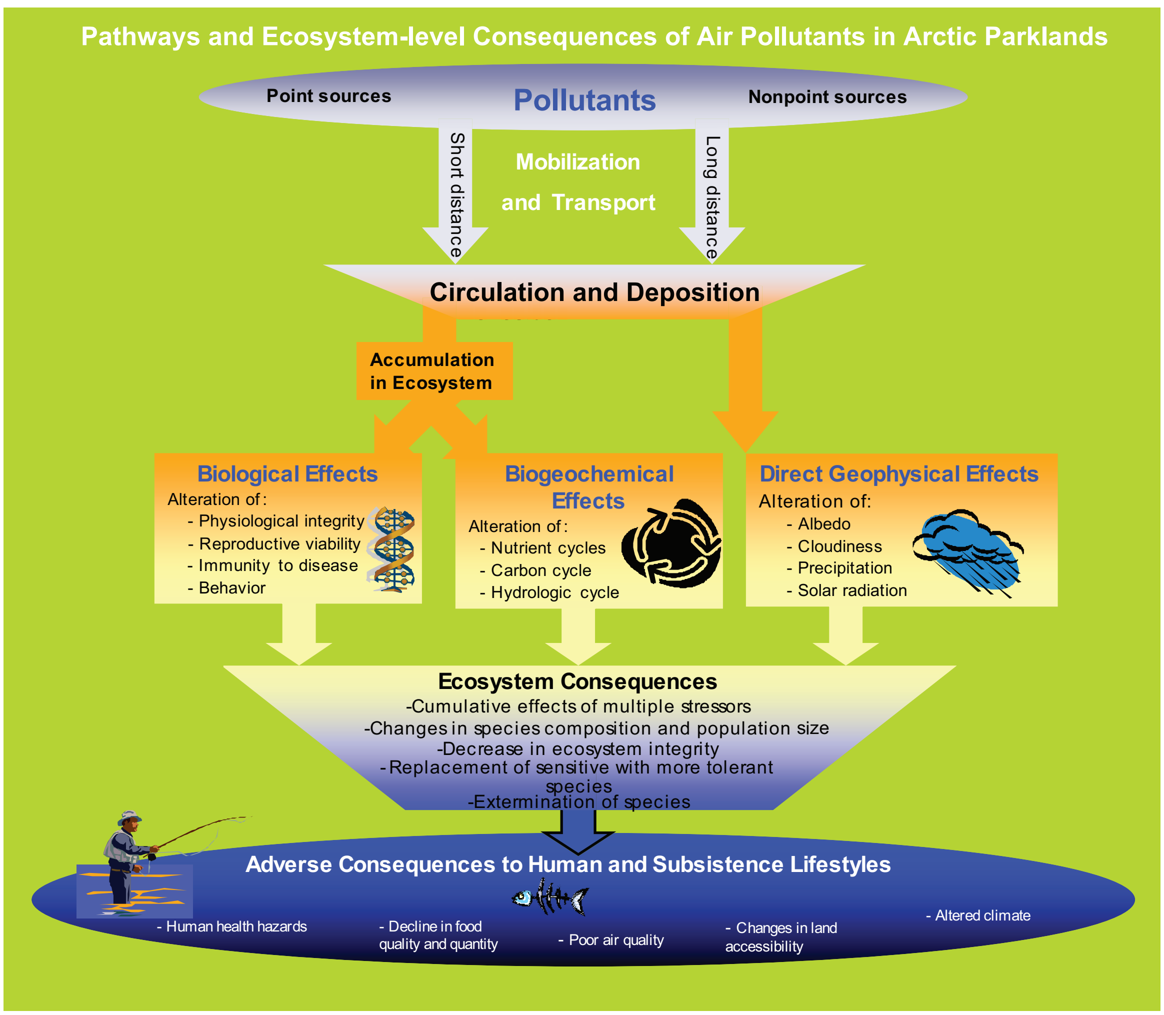


Figure 30. Potential pathways and ecosystem-level consequences of air pollutants in arctic parklands.

Humans and their subsistence lifestyles are also directly impacted by these air toxins and their effects. Some of these toxins are human health hazards and increased exposure to the toxins should lead to increased morbidity. Mercury is a prime example of an air toxin that could lead to adverse health effects in humans living in the Arctic. The air quality in the parks could also deteriorate quality and quantity of food sources. The availability and quality of subsistence foods could deteriorate due to increased stress on terrestrial and aquatic ecosystems, causing changes in habitat, migration patterns of subsistence species, or overall decreased numbers of desired food species. The accessibility of the land may also change if precipitation patterns, melt/thaw periods, etc. change due to alteration of geophysical processes and hydrological cycles. This would impact subsistence lifestyles by decreasing the accessibility of food species. For example, it is much harder to hunt caribou in soggy tundra than on a solid snow surface. Lastly, climate change may be exacerbated by the air toxins through the increased trapping of heat by greenhouse gases and low-level cloud cover. This could have dramatic effects on the people and animals of the ARCN parklands. The changing climate could lead to changes in ecosystem type, animal viability, land accessibility, etc. that could make a subsistence lifestyle based on the ARCN parks' resources untenable.

A Conceptual Framework for Considering Migratory and Invasive Species of the Arctic Network

Invasive species are those which have changed their distribution and colonized new areas. Current examples within ARCN would be various weedy plants that have established themselves in disturbed areas near villages and along roads. Invasive species can also be native species that have increased their populations and impact on native ecosystems to an important degree. The enormous and destructive rise in bark beetle populations in the spruce forests of southcentral Alaska is a good example of this. Both of these types of situations exist, generally on a small scale, within ARCN. Another common phenomenon, especially in northern environments, is the cyclical rise and fall, often by an order of magnitude or even much more, of populations of native species. While the classic examples of this are various microtine rodents (voles and lemmings) it also occurs in other species, including caribou. There are also migratory species whose breeding location and population status may change radically over time. Several species of Siberian birds (e.g., white wagtail) have colonized western Alaska in recent decades. The known examples of invasive species are mostly conspicuous organisms, but it is probable that invertebrates and certain plants will be found to show similar changes in distribution.

Invasions by "foreign" organisms usually depend on much more than simply the opportunity provided by an unusual (usually anthropogenic) dispersal event. Generally more important are changes in the local environment that allow individuals or propagules from the invasive organisms to establish themselves in areas from which they were previously excluded by ecological conditions. These can be simple changes such as the disturbance of the soil surface, encouraging the growth of ephemeral weeds, or complex alterations in the environments brought about by changing climate. These latter owe much of their complexity to the fact that they are seldom straightforward. The ultimate effect of a climatic change may result from an array of factors: changes in competition or predation as other species are eliminated or favored, changes in precipitation and/or hydrology and permafrost regime that favor certain species, or changes in soil chemistry due to human activities that inhibit otherwise common species and thus provide a habitat with reduced competition for resistant species.

Some "invasions" are actually the reestablishment of species that had previously been reduced or extirpated. Muskoxen in western Alaska are a good example. Others seem to be natural reexpansion, such as the case of grizzly bears on the Seward Peninsula in recent decades. Many of these population reestablishments or expansions are actively encouraged by managers, as for example, the efforts to encourage waterfowl such as emperor geese and spectacled eider along the Bering Sea coast.

When viewed in the above context, it should be clear that invasive species, or changes in the distribution and abundance of species, are not only of intrinsic interest but are also likely to be important bellwethers in identifying deeper, more profound, and widespread changes in ecosystems (Figure 31). They can be expected to be of great significance in the construction of monitoring programs.

Invasive Species Pathways in ARCN

Although environmental factors are likely to be primary in determining the fate of an invasive species, the importance of dispersal routes and mechanisms should not be overlooked (Figure 32). In many cases, of course, a dispersal route also represents an area of environmental alteration. The berms of a gravel roadbed, for example, will normally have very different drainage and soil characteristics from the surrounding unaltered environment. A roadbed may then provide a highway for the spread of weedy species far beyond their normal range. Even a trail that is regularly used by ATVs or snowmobiles may have a similar, although usually less marked, effect.

Even low-impact recreational activities can provide dispersal opportunities for exotic organisms. Camping gear can transport seeds, the floats and hulls of amphibious aircraft can transport propagules of plants from lake to lake, and canoes and kayaks can effectively move plants down a river drainage. The following diagram shows some specific examples of how plants and animals might move about as a result of human activities.

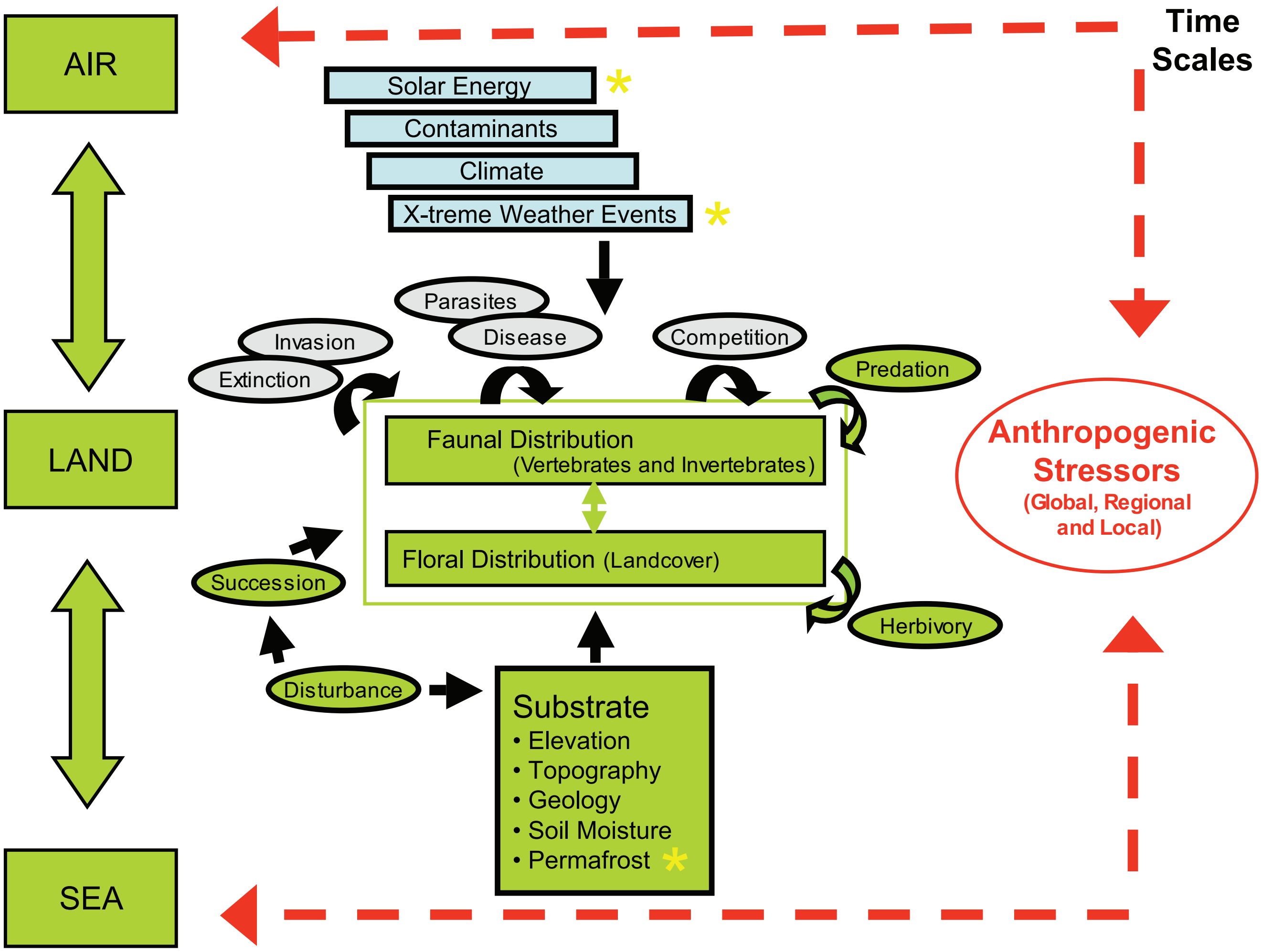


Figure 31: A graphic representation of the complex of factors that may be involved in changes in distribution of migratory and invasive organisms over time in ARCN.

Figure 32: Examples of possible routes and vectors for the dissemination of exotic species within ARCN. Red lines are existing or proposed (RS 2477) roads or trails.

Literature Cited

Alaska Dept. of Fish and Game. 1978. *Alaska's Wildlife and Habitat: Volume II.* Juneau, AK.

Arctic Monitoring and Assessment Programme. 1997. *Arctic Pollution Issues: A State of the Arctic Environmental Report.* Arctic Monitoring and Assessment Programme, Oslo.

Black, R. A., and R. C. Bliss. 1978. Recovery sequence of *Picea mariana-Vaccinium uliginosum* forests after burning near Inuvik, Northwest Territories, Canada. *Canadian Journal of Botany* 56: 2020–2030.

Boertje, R. D. 1984. Seasonal diets of the Denali caribou herd, Alaska. *Arctic* 37(2): 161–165.

Bradley, R. S. 1999: *Paleoclimatology: Reconstructing Climates of the Quaternary.* San Diego, Academic Press. 613 pp.

Burns, C.E., K. M. Johnston, and O. J. Schmitz. 2003. Global climate change and mammalian species diversity in U.S. national parks. *Proceedings of the National Academies of Science* 100: 11474–11477.

Chapin, F. S., E. S. Zavaleta, V. T. Eviner, R. L. Naylor, P. M. Vitousek, H. L. Reynolds, D. U. Hooper, S. Lavorel, O. E. Sala, S. E. Hobbie, M. C. Mack, and S. Díaz. 2000. Consequences of changing biodiversity. *Nature* 405: 234–242.

Christiansen, J. S. 1988. A spruce-lichen woodland in northern Alaska: Post-fire regeneration and community dynamics. M.S. Thesis, University of Washington. Study Area: Walker Lake.

Coady, J. W. 1980. History of moose in northern Alaska and adjacent regions. *Canadian Field Naturalist* 94: 61–68.

Craig, P.C., and P. McCart. 1975. Classification of stream types in Beaufort Sea drainages between Prudhoe Bay, Alaska, and the Mackenzie Delta, N.W.T. *Arctic and Alpine Research* 7: 183-198.

Dissing, D., and D.L. Verbyla. 2003. Spatial patterns of lightning strikes in interior Alaska and their relations to elevation and vegetation. *Canadian Journal of Forest Research* 33: 770-782.

Elias, S. A., and J. Brigham-Grette. 2000. Beringian paleoenvironments. *Quaternary Science Reviews.* Elsevier, London, 574 pp.

Ford, J., and T. Vlasova. 1996. Airborne contaminants in vegetation of arctic Alaska and Russia. Pp. 159–168 in R. Meehan, V. Sergienko, and G. Weller (eds.) *Bridges of Science Between North America and the Russian Far East.* Arctic Division, AAAS, Fairbanks, AK.

Gerson, U. 1973. Lichen-arthropod associations. *Lichenologist* 5: 434–443.

Gross, J.E. 2003. *Developing conceptual models for monitoring programs.* NPS Inventory and Monitoring Program, Ft. Collins.

Gunther, A. J. 1989. Nitrogen fixation by lichens in a subarctic Alaskan watershed. *Bryologist* 92(2): 202–208.

Hinzman, L., and C. Vörösmarty, eds. 2001. *NSF-ARCSS Workshop on Arctic System Hydrology: Meeting White Papers.* Fairbanks, Alaska: Arctic Research Consortium of the U.S., 86 pp.

Hopkins, D.A., J. V. Matthews, C. S. Schweger, and S. B. Young. 1982. *Paleoecology of Beringia.* New York, Academic Press. 489 pp.
Hulten, E. 1937. *Outline of the History of Arctic and Boreal Biota During the Quaternary Period.* Stockholm.
Hulten, E. 1968. *Flora of Alaska and Neighboring Territories.* Stanford.
Jenkins, J.A., L. DeCola, C.C. Barton, J. Buys, and F.T. Manheim. 2003. Nonlinear approaches to understanding human and environmental health [abs.], in *USGS Conference on Natural Science and Public Health; Prescription for a Better Environment:* U.S. *Geological Survey Open-File Report 03-097* (unpaginated).
Jepson, P.D., P.M. Bennett, C.R. Allchin, R.J. Law, T. Kuiken, J.R. Baker, E. Rogan, and J.K. Kirkwood. 1999. Investigating potential associations between chronic exposures to polychlorinated biphenyls and infectious disease mortality in harbour porpoises from England and Wales. *Science of the Total Environment* 243/244: 339-348.
Joyce, M.R. 1980. Effects of gravel removal on terrestrial biota. Pp. 215–272 in Woodward-Clyde Consultants (eds.), *Gravel Removal Studies in Arctic and Subarctic Floodplain in Alaska—Technical Report. U.S. Fish Wildl. Serv., Biological Services Program, FWS/OBS-80/08.*
Lent, P. 1999. Alaska's indigenous muskoxen: A history. *Rangifer* 18: 3–4.
Mack, M. C., E. A. G. Schuur, M. S. Bret-Harte, G. R. Shaver, and F. S. Chapin III. 2004. Ecosystem carbon storage in arctic tundra reduced by long-term nutrient fertilization. *Nature* 431: 440–443.
Markon, C. J., and S. D. Wesser. 1997. The Bering Land Bridge National Preserve Land Cover Map and its Comparability with 1995 Field Conditions. Open File Report 97-103. U.S. Geological Survey.
Markon, C. J., and S. D. Wesser. 1998. The Northwest Alaskan Parks Land Cover Map. Open File Report. U.S. Geological Survey.
McCune, B. 1988. Lichen communities along O_3 and SO_2 gradients in Indianapolis. *The Bryologist* 91: 223–228.
McRoy, C.P. 1968. The distribution and biogeography of *Zostera marina* (eelgrass) in Alaska. *Pac. Sci.* 22: 507-513.
Nash, T. H., III, and V. Wirth (eds.) 1988. Lichens, bryophytes, and air quality. *Bibliotheca Lichenologica* 30. J. Cramer, Berlin-Stuttgart.
National Research Council. 2003. *Cumulative Environmental Effects of Oil and Gas on the North Slope.* Washington, DC: National Academies Press.
Neitlich, P.N., and L. M. Hasselbach. 1998. Lichen inventory and status assessment for Gates of the Arctic National Park, Alaska. NPS General Technical Report, Fairbanks, Alaska.
Noon, B.R. 2003. Conceptual issues in monitoring ecological resources. Pp. 27-71 in D.E. Busch and J.C. Trexler (eds.), *Monitoring ecosystems: Interdisciplinary Approaches for Evaluating Ecoregional Initiatives.* Island Press, Washington, D.C.

NPFlora. 1989. Checklist of flora and fauna in collections of national park units in Alaska. U.S. Department of Interior, National Park Service, Alaska Regional Office, Anchorage, Alaska.

NPSpecies: The National Park Service Biodiversity Database. Secure online version. https://science1.nature.nps.gov/npspecies/ (accessed September 2004).

O'Neill, R.V., D.O. DeAngelis, J.B. Waide, and T.F.H. Allen. 1986. *A Hierarchical Concept of Ecosystems.* Princeton University Press, Princeton, NJ.

Oswood, M.W. 1997. Streams and rivers of Alaska: A high latitude perspective on running waters. Pp. 351-356 in A.M. Milner and M.W. Oswood (eds.), *Freshwaters of Alaska: Ecological Syntheses.* Springer-Verlag, New York.

Pegau, R. E. 1968. Growth rates of important reindeer forage lichens on the Seward Peninsula, Alaska. *Arctic* 21: 255–259.

Racine, C., R. Jandt, C. Meyers, and J. Dennis. 2004. Tundra fire and vegetation change along a hillslope on the Seward Peninsula, Alaska, U.S.A. *Arctic, Antarctic and Alpine Research* 36: 1-10.

Richardson, D. H. S. 1992. *Pollution Monitoring with Lichens.* Richmond Publishing, Slough.

Sharnoff , S., and R. Rosentreter. 1998. Wildlife uses of lichen in North America. On line: http://www.lichen.com/fauna.html.

Stottlemyer, R. 2001. Biogeochemistry of a treeline watershed, northwestern Alaska. *Journal of Environ. Qual.* 30(6): 1990-8.

Swanson, J. D., M. Schuman, and P. C. Scorup. 1985. Range survey of the Seward Peninsula Reindeer Ranges, Alaska. U.S. Department of Agriculture: Soil Conservation Service.

Thornton, K.W., Hyatt, D.E., and C.B. Chapman, eds. 1993. *Environmental Monitoring and Assessment Program guide.* EPA/620/R-93/012. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.

Tibbitts, T. L., D. Ruthrauff , R. E. Gill, and C. M. Handel. 2003. Inventory of montane-nesting birds in national parks of northwest Alaska: A summary of the 2001 and 2002 field efforts. U.S. Geol. Surv., Alaska Science Center, Anchorage, Alaska.

The Nature Conservancy. 1999. The National Vegetation Classification System. Online national vegetation classification at www.tnc.org (or) http://consci.tnc.org/library/pubs/class.

Uhl, W.R., and C.K. Uhl. 1980. *Tagiumsinaagmiit, ocean beach dwellers of the Cape Krusenstern Area: Subsistence Patterns.* University of Alaska, Cooperative Park Studies Unit, Fairbanks Alaska.

Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. *The Alaska Vegetation Classification.* U.S. Department of Agriculture: Forest Service. Pacific Northwest Research Station. General Technical Report PNW-GTR-286, July 1992.

Vörösmarty, C.J., L.D. Hinzman, B.J. Peterson, D.H. Bromwich, L.C. Hamilton, J.Morison, V.E. Romanovsky, M.Sturm, and R.S. Webb.

2001. The Hydrologic Cycle and its Role in Arctic and Global Environmental Change: A Rationale and Strategy for Synthesis Study. Fairbanks, Alaska: Arctic Research Consortium of the U.S.

Wiig, O., A.E. Derocher, M.M. Cronin, and J.U. Skaare. 1998. Female pseudohermaphrodite polar bears in Svalbard. *Journal of Wildlife Diseases* 34: 792–796.

Young, S. B. 1971. The vascular flora of St. Lawrence Island with special reference to floristic zonation in the arctic regions. *Contributions from the Gray Herbarium* 201: 11–115.

Young, Steven B. 1974. The environment of the Noatak River Basin, Alaska: Results of the Center for Northern Studies biological survey of the Noatak River Valley, 1973. Contributions from the Center for Northern Studies. Fairbanks, AK: Center for Northern Studies.

Young, S. B. 1989. *To the Arctic.* New York: Wiley and Sons. 354 pp.